QUARTERLY REPORT 1

PROJECT A-786

PHYSICS OF SEAM PUCKER

JAMES L. TAYLOR

Contract 12-14-100-7193(72)

12 June to 12 September 1964

Prepared for
U. S. Department of Agriculture
Southern Utilization Research and Development Division
New Orleans, Louisiana

1964

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

GEORGIA INSTITUTE OF TECHNOLOGY
A. French Textile School
Atlanta, Georgia

QUARTERLY REPORT 1

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By

JAMES L. TAYLOR

CONTRACT 12-14-100-7193(72)

12 JUNE TO 12 SEPTEMBER 1964

Prepared for
U. S. DEPARTMENT OF AGRICULTURE
SOUTHERN UTILIZATION RESEARCH AND DEVELOPMENT DIVISION
NEW ORLEANS, LOUISIANA

ABSTRACT

The work on this project began with a series of meetings with manufacturers of garments, sewing threads, and fabrics which will be used in the experimental work.

Determination of the availability of various wash-wear treatments for the fabrics was made. Arrangements have been made to obtain four types of cloth treated with suitable resins.

Wash-wear treated sewing threads are not in commercial use. Small lots of specially finished thread with wash-wear treatments specified in the project will be obtained from Coats & Clark, Inc.

Preliminary discussions have been conducted with various sewing machine manufacturers in regard to the type of machines needed for this investigation.

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This report contains 7 pages

I. INTRODUCTION

The purpose of the proposed research is to develop improved cotton sewing thread for wash-wear fabric structures, compatible with existing high speed sewing manufacturing methods, which will not cause seam pucker, or which will have a markedly reduced tendancy to cause ~~seam~~ pucker, thereby facilitating increased consumer acceptance, thus expanding the markets for resin treated wash-wear cotton.

The first quarter's work included familiarization of the problem of seam-pucker in wash-wear treated cotton fabrics. This included comments, advice and data from many companies and private individuals. A literature survey has also been made on the subject.

The investigators sought, and continued to seek, assistance of anyone who has worked on any aspect of this problem. Response to inquiries made has been excellent and many new leads to further information has been offered.

II. EXPERIMENTAL WORK

This program began on June 12, 1964 with a visit to the research laboratories of Coats & Clark, Inc. at Newark, New Jersey. At this time conferences were held with Mr. Eckhardt, Head of the Research Unit; Mr. Sperling, Head of Physical Properties; and Dr. Guenther, Head of Chemical Properties. It was ascertained that Coats & Clark was not applying to its threads any of the wash-wear treatments mentioned in the proposal. However, work with similar compounds had been done previously. The results of these previous investigations will be made available to Georgia Tech. In addition, Mr. Eckhardt agreed to have selected threads treated with the wash-wear treatments mentioned in the proposal, so that these threads can be evaluated.

A meeting was held on June 15, with Mr. Berard, U. S. D. A. representative, and Mr. Frederick, Chief Seams Research Laboratory, U. S. Army Natick Laboratories, at Natick, Massachusetts. Mr. Frederick outlined the work which the U. S. Army had done on seam pucker in the past and their present thinking on the subject. A copy of the current Federal Specifications VT 276E on thread recommendations for threads meeting these specifications were received from this laboratory.

Another meeting was held on June 17th with Mr. Fields, Research Director of the American Thread Company Laboratories, Willimantic, Connecticut. It was learned that this company does not employ any of the wash-wear treatments listed in the contract on its threads at this time. Work with similar compounds has been done in the past and the results of this work will be made available. Mr. Fields offered several sources of other data on the problem including the recent patents and two publications of the British Clothing Institute.

Several meetings have been held with members of the staff at Cluett Peabody Company Arrow Shirt Plant here in Atlanta. This company offered its help on the project including the finishing of fabric in their finishing plant.

Cluett Peabody has done considerable work on the problem of seam puckering. Results of these investigations will be made available to Georgia Tech. In addition to discussion of wash-wear type fabrics, discussions emphasizing sewing techniques currently in use to minimize puckering were held. Various makes and models of commercial sewing machines were discussed as well as the fittings used for the best results on each type.

Meetings have also been held with other garment manufacturers in Atlanta. These represent both mens and ladies wear garments. In every instance the garment manufacturers have expressed a sincere interest in the program. Many have had difficulty with sewing of wash-wear garments.

A visit has also been made to the Deering Milliken Research Laboratory at Spartanburg, South Carolina. Meetings were held with Mr. Gardner and Mr. Comstock, of that laboratory, both of whom have had several years of experience on the problems of seam puckering. Mr. Gardner is co-author of a booklet on the handling of Belfast treated fabrics during sewing. This laboratory has offered to cooperate with the investigators to the extent that they are willing to apply the resins in their pilot plant at Spartanburg.

Contacts have also been made with the Thomaston Mills at Thomaston, Georgia, to ascertain their interest in applying wash-wear treatments other than Belfast on broadcloth and oxford cloth. This company also showed interest in the program and offered their help wherever possible. The Dan River Mills at Danville, Virginia, has been contacted and have offered their assistance on this program, particularly in the application of resins to gingham and other similar type fabrics.

A trip was made to Alexander City, Alabama, to discuss this problem with Mr. Joe Richardson, Plant Manager of Russell Mills Company. Mr. Richardson also offered help in applying resins to fabrics which are commonly finished in his plant. Many samples were examined while visiting this plant and it was learned that it was rather difficult to get a number 4-AATCC rating on chambray and print cloth fabrics.

During the month of August a series of visits were made to users or suppliers of print cloth. It was observed that the finishing plant finishes cloth to a known specification, however the customer usually buys on style and appearance without knowledge of the chemical finishing supplied. The use of various hang tags were explored to determine the accuracy of the trade names when interpreted to mean specific chemical treatment. It was determined that a given style of fabric in a given year will be treated in a specific way. This treatment may enhance the sewability or may reduce it. The treatment remains substantially the same throughout the selling season. Another similar fabric may have a slightly different treatment which is softer or drapes better, etc. Both fabrics may have been treated with the same basic wash-wear chemical but in varying amounts and with softeners and starches added separately to give desired appearance to finished goods.

A literature research has been completed. All available references located through this search have been abstracted and distributed to scientists working on this project. Additional material has been ordered from the Technical Advisory Committee of the American Apparel Manufacturers

Association and from the American Association of Textile Chemists and Colorists. Copies of two pertinent technical bulletins of the Clothing Institute, London, have been ordered. A photocopy of Clothing Institute's Technical Bulletin 10 has been obtained so that the work already done can be evaluated.

Measurement of seam pucker by photometric methods is being investigated. This work seeks to measure variations of output when using a photo-electric system to observe specimens which exhibit varying degrees of puckering. It appears that a masking or collimator system must be constructed to limit the field of view to the puckered areas when using present instruments.

III. DISCUSSION

The investigations thus far indicate that, although seam pucker is a current problem, much of the research on the causes was undertaken over ten years ago. Some work is continuing but the consensus of opinion of several former investigators is that the causes of seam pucker are now known. Although very little work on the basic physics of seam pucker is in the literature, the present investigators have access to various unpublished studies which should prove very helpful.

IV. CONCLUSIONS

The work is proceeding according to plan. Established sources of fabrics, threads and machines appear to be adequate for the next quarter's work. One conclusion already apparent is that this project will bring together at one point data which heretofore has not been available or known to early investigators.

The plan for the second quarter includes contact with consumer groups to obtain their evaluation of problems. Experimental work on the basic fabrics will be started as soon as they are delivered. Special finishing of thread with wash-wear treatments will be arranged. Sewing tests and physical tests will be made.

QUARTERLY REPORT 2

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QUARTERLY REPORT 2

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By

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CONTRACT 12-14-100-7193(72)

12 SEPTEMBER to 12 DECEMBER 1964

Prepared for
U. S. DEPARTMENT OF AGRICULTURE
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NEW ORLEANS, LOUISIANA

ABSTRACT

Work during second quarter was curtailed by a delay in receiving the test fabrics.

Photo-electric instrumentation for measurement of pucker shows promise. Work being done includes the design of a portable instrument for this purpose. Specially sewed dummies of men's wash-wear treated shirts were used to determine the discrimination needed to measure the amplitude of puckering.

Delivery of wash-wear treated threads is expected during December. The chemicals used are those currently produced by the larger chemical companies for wash-wear treatment of fabrics.

Industrial interest in this project continues, among thread companies particularly.

Union Special Machine Co. has agreed to supply sewing machines for this project.

TABLE OF CONTENTS

This report contains 6 pages

I. INTRODUCTION

Work had been planned for the second quarter on the assumption that test fabrics and threads would be delivered fairly early during the period. Various difficulties, which are discussed in the next section, have delayed delivery on these materials.

Work on the design of measurement instrumentation and other aspects of this project proceeded according to plan.

II. EXPERIMENTAL WORK

Work done during the second quarter falls into six categories which will be discussed separately. They are:

a. Typical sewing problems on men's wash-wear treated cotton shirts. While preparing preliminary tests of the instrumentation needed for measuring seam pucker, it was decided to obtain actual samples of puckered work from a typical sewing room for use in these tests.

The Quality Control Manager of Cluett Peabody Co.'s (Arrow Shirt Co.) plant in Atlanta prepared dummies embodying various sewing problems. These dummies were very carefully sewed to illustrate problems of operator manipulation in pocket attaching, of differential puckering on top stitched collars, of puckering in making and attaching cuffs, of forming plackets, etc.

Three different fabrics were used, each sewed with the threads now used in Arrow's sewing rooms. These fabrics were 100% cotton combed broadcloth treated with a resin finish, 100% cotton combed broadcloth with Belfast finish and a blended dacron cotton batiste with resin finish. A separate group of Dectoline dummies were examined but no comparison between them and the cotton samples was attempted

The dummies prepared by Arrow Shirt Co. were considered to be typical examples of manufacturing pucker which is visible and must be evaluated by a final inspector before boxing the shirts for shipment. Therefore they could be used as typical of the probable extent of manufacturing pucker which might be accepted or rejected among the dummies.

b. Photometric methods of measuring the degree of seam pucker were studied using the Arrow Shirt Co's dummies and a Model 594 Weston

Photronic cell setup in a dark room. Power was supplied from a constant voltage electric source to an American Optical Co.'s microscope illumination source. Readings were obtained on a microammeter which was connected to the cell through a resistance decade which was in series with the microammeter.

The light source was arranged to illuminate the puckered cloth sample at an incident angle of about 45°. The photocell, collimated by a long non-reflecting tube, was arranged to look down (vertically) at a masked portion of the puckered seam. The reading on the microammeter was noted. The sample was then rotated through 360° while observations of the output registered on the microammeter were noted.

It was determined that the sensitivity of this particular cell was sufficient to achieve the desired discrimination.

If further tests indicate that greater discrimination is needed, a much more sensitive AMINCO Photomultiplier, which is sensitive to illumination changes of 10^{-12} lumens, is on hand.

In previous studies of textile fabrics this photomultiplier proved sufficiently sensitive to determine the warp from the filling direction in the weave of a particular fabric being rotated through 360° below it.

If the sensitivity proves to be as good as expected, arrangements will be made to build a portable apparatus employing the major parts described above. The output will be fed into a recorder.

The relative area under the curve for unpuckered and puckered samples is expected to provide a measurement of the degree of pucker. In this study each puckered fabric will be zeroed against an unpuckered sample of itself.

The incident angle of approximately 45^{o} was chosen for initial tests. It is not known at this time whether greater discrimination can be obtained at other angles.

<u>c. Coats and Clark Research Laboratory</u> agreed to produce very small quantities of typical cotton sewing threads treated to give wash-wear characteristics . It has been over ten years since their earlier work with these treatments. In this time techniques and materials have changed. Therefore the staff of that laboratory decided to repeat their earlier work and include current knowledge of the problem. They were satisfied by the results. Threads that are being delivered this month will have been treated with the materials currently furnished by large chemical companies for the wash-wear treatment of cotton fabrics.

<u>d. Union Special Machine Co.</u> has agreed to furnish sewing machines for this project. Delivery of the first machine, Type 63400 U or V, is planned for December. The company will also furnish technical assistance on its equipment.

<u>e. Additional literature on the problem was obtained</u>. Technical Reports 8 (on Shrinkage) and 10 (on Seam Pucker) were received from the Clothing Institute. The staff of the institute suggested that a more recent Technical Report 12 on shrinkage was also relevant. Copies have been ordered.

<u>f. Four fabrics for this project were woven by Deering Milliken.</u> Scheduling problems delayed production of the gingham. Since it was planned to treat all four fabrics at the same time, this delay caused postponement

of all treatments. The treatments have now been applied. The fabrics will be delivered after final finishing in late December. The fabrics are:

	Width (Inches)	Construction (Ends by Picks)	Weight (Yards /Pound)
BROADCLOTH	47"	136 x 64	2.65
OXFORD	47"	88 x 50	2.85
PRINT CLOTH	48"	80 x 80	3.30
GINGHAM	46"	84 x 66	3.79

III. CONCLUSIONS

Further study of the techniques of photometric measurement of seam pucker is warranted. The approach of designing a portable instrument suitable for use in the sewing plant as well as the laboratory will be continued.

Acceleration of the program of test sewing will bring the project on schedule during the third quarter.

Continued interest in this project has been expressed in letters from American Thread Co., Belding Heminway Co., Inc. and Textile Fibers Department, I. E. du Pont de Nemours & Co., Inc.

QUARTERLY REPORT 3

PROJECT A-786

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JAMES L. TAYLOR

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QUARTERLY REPORT 3

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PHYSICS OF SEAM PUCKER

By

JAMES L. TAYLOR

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ABSTRACT

Deering Milliken delivered four lots of test fabrics in late December. Each lot contained an untreated roll, a Permafresh 183 finish roll and a roll of Belfast fabric. These print cloth, oxford, broadcloth and gingham fabrics will be sewed with both single and double needle machines. Work on untreated print cloth sewed with soft finish untreated thread was begun using a Union Special Machine Company single needle lockstitch machine. The thread used was part of four sizes of test threads delivered by Coats and Clark in soft and mercerized finishes. Portions of each thread size and finish in both cured and uncured states were supplied in both DMEU and triazine finishes.

Photoelectric measurement of seam pucker shows promise. Close correlation was noted between the curves traced by the recorder and photomicrographs of the same puckered area. Samples of these curves and photomicrographs are included in this report.

TABLE OF CONTENTS

This report contains 12 pages.

I. INTRODUCTION

Delivery of the four test fabrics by Deering Milliken Company and of the different test threads by Coats and Clark Company in late December 1964, made it possible to proceed with the planned program of work during this quarter. A physical evaluation of the fabrics was made and the cones of thread were carefully catalogued.

The first sewing cycles using a single needle lockstitch machine furnished by Union Special Machine Company were started. This work was begun near the end of the current quarter and it is anticipated that a number of these cycles will have been completed prior to the end of the next quarter.

Considerable progress was made in the development of an instrument to measure puckering photoelectrically. In addition, refinements were made in the analysis of the curves produced so that there is better correlation between the visual ratings and machine measurements. More evaluation work will be accomplished during the coming quarter.

II. EXPERIMENTAL WORK

Work done during the 3rd Quarter falls into seven categories:

A. Photoelectric Measurement of Pucker

1. Methods of measuring the amplitudes and extent of seam pucker, as described in Quarterly Report 2, have been developed further. The illuminator used initially was operated from the regular 115 volt commercial electrical service. The background noise detected in the instrument could not be isolated, so it was decided to try a battery operated illuminator. A 6 volt headlight bulb was substituted for the 115 volt microscope lamp source. The noise level was greatly reduced and is now acceptable.

2. The battery operated lamp assembly was repositioned directly over the seam being scanned. With the incident light at 90°, it then became possible to vary the angle at which the reflected light reached the photometer. Initially 45° was used, but after experimenting with several other angles, 30°, was selected for work being done during the 3rd Quarter.

3. A Photovolt Corporation Model 514M photometer was used for work during the 3rd Quarter. This photometer was chosen because it is also battery operated.

4. The original instrument used rotary motion to pass the sample through 360° while readings were being taken. Evaluation of the results of this work led to the conclusion that the difficulty in interpretation, caused by the rotary geometry compared to the visual object, needlessly complicated the problem. This determined that translational motion would provide a better comparison. By passing the sample below the photometer at a constant rate,

a direct shadow position comparison could be made. A milling vise was obtained and used as a support for the samples. By utilizing a reversible motor attached to the driving screw, the bed of the vise could be driven at a uniform rate under the incident light beam. Upon completion of the trace in the direction in which sewing had been done originally, it was possible to retrace in the opposite direction to obtain a second curve of the same area.

5. Recordings of the trace of each seam were made on an X-Y recorder using a time base drive on the abscissa. This recorder allowed flexible settings of sweep and amplitude. Measurement of several samples at a fixed rate of 9 inches per minute indicated that about 6-8 inches per minute will produce curves with sufficient spread for accurate interpretation.

6. Variations in puckering displayed by three seams all judged "poor" by Arrow Shirt Company standards were measured by this technique. Figures 1, 2 and 3 show the curves and photomicrographs of these seams. Comparison of the curves to the seams shows excellent correlation.

7. An analysis was made of the curves resulting from various experiments during the 3rd Quarter. Although the sample size was too small for conclusive evidence, there is reason to continue study of the extent of the areas resulting from deviations around the center line of each trace. This may be one way of determining the nature of the puckering being encountered in a given sample.

B. Physical Characterization of Test Fabrics

The test fabrics were physically characterized in the Standard Conditioned

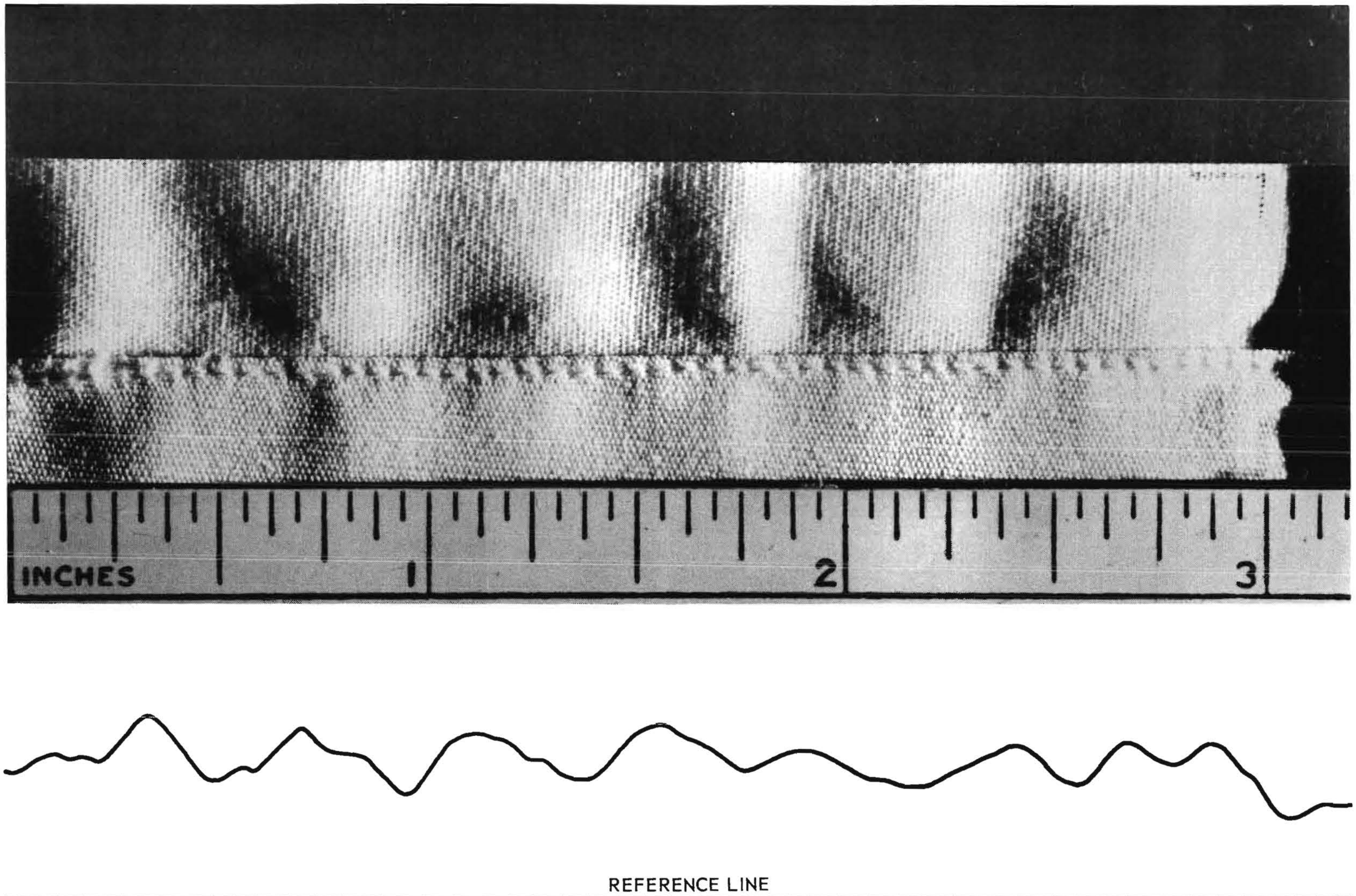

Figure 1. Curve and Photograph of a Seam Judged Poor.

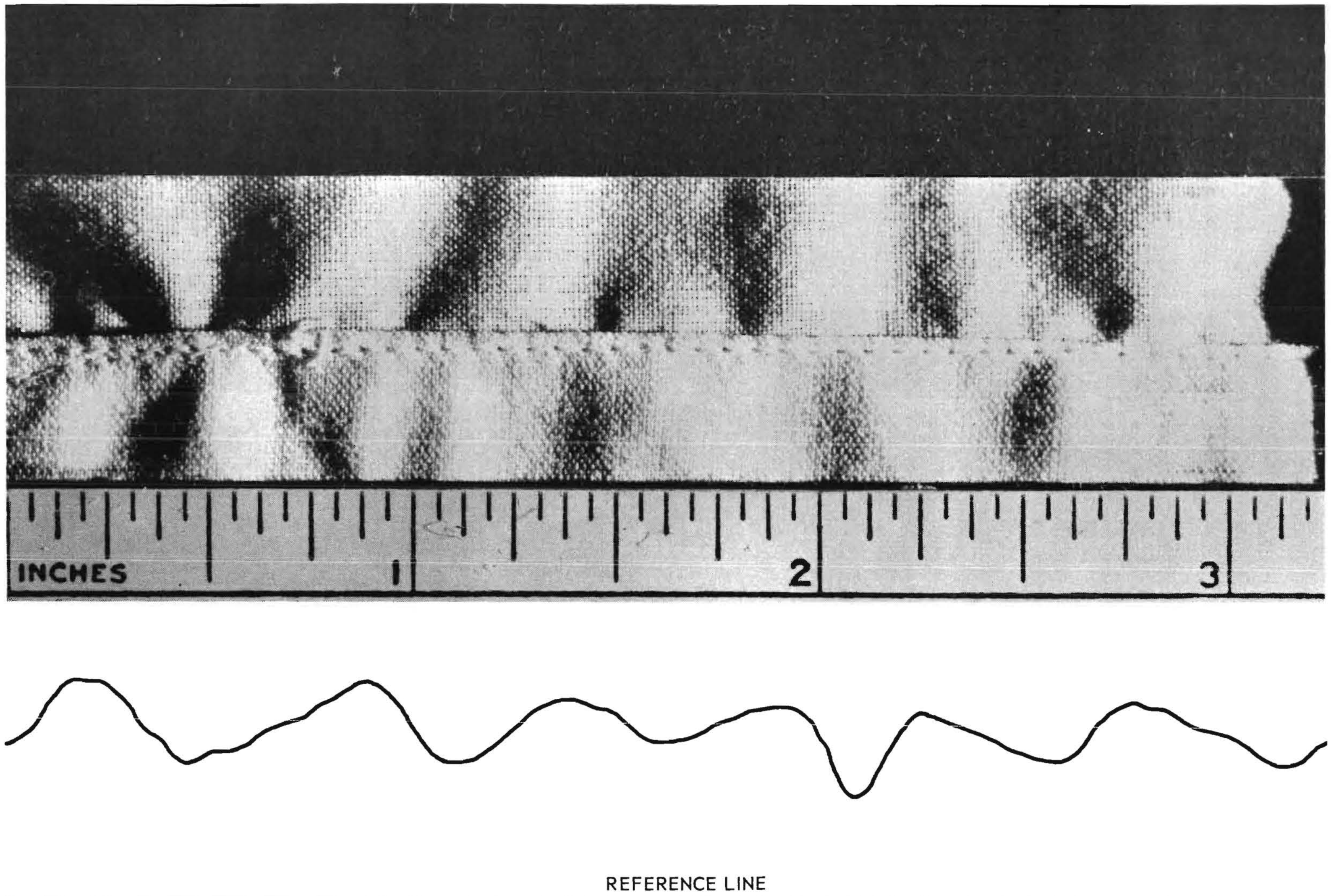

Figure 2. Curve and Photograph of a Seam Judged Poor.

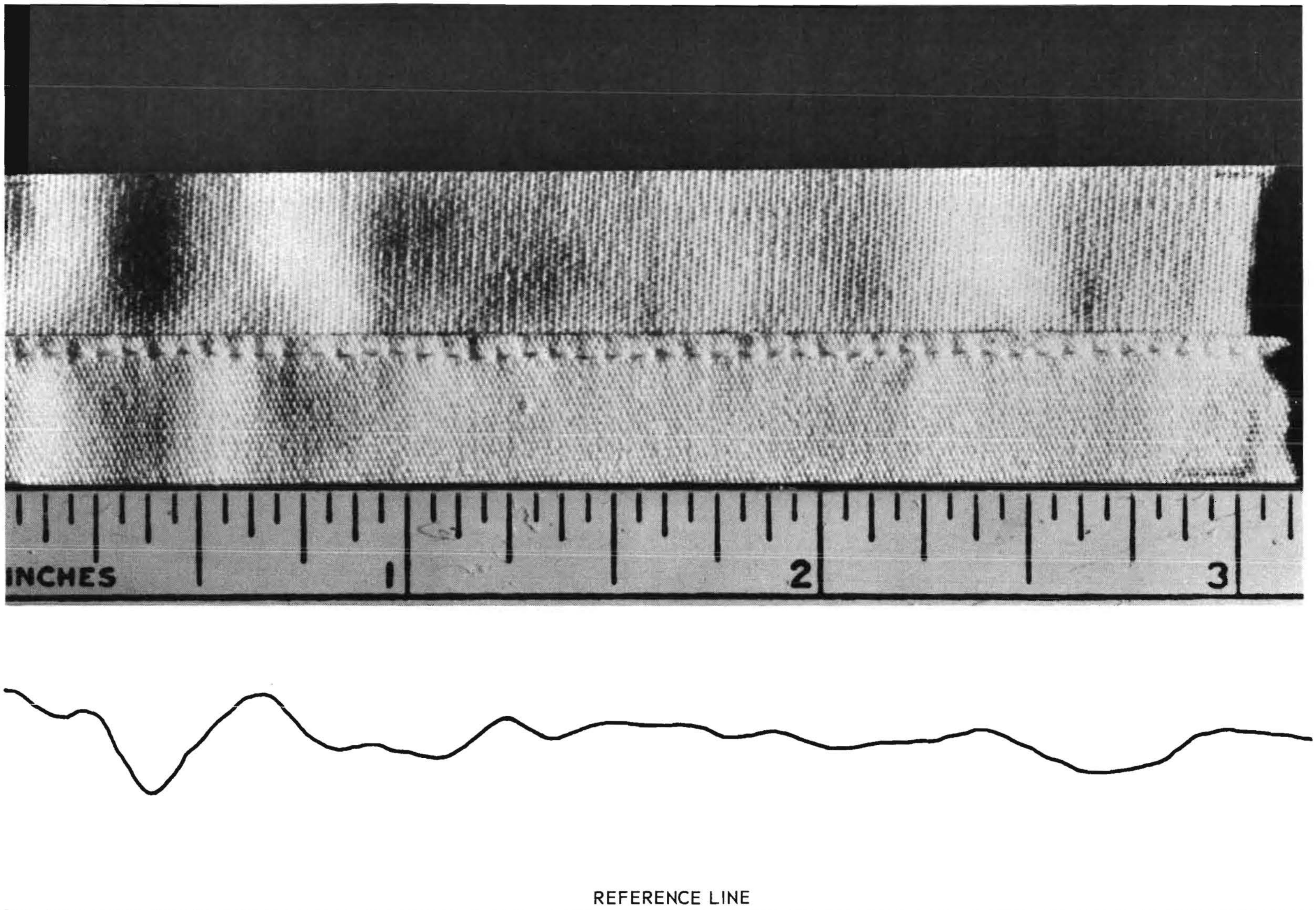

Figure 3. Curve and Photograph of a Seam Judged Poor.

Testing Laboratory. The result of this analysis is given below in Table I.

TABLE I

TEST FABRICS

Greige Constructions	E/in.	P/in.	Width
Print Cloth	80	80	48"
Broadcloth	136	64	47"
Oxford	88	50	47"
Gingham	84	66	46"

Finished Constructions

FABRIC		CONSTRUCTION E/in.	CONSTRUCTION P/in.	GRAB STRENGTH Warp (lbs)	GRAB STRENGTH Filling (lbs)	WEIGHT Oz/Yd^2
Print Cloth						
Belfast	(A)	87	78	36.9	23.0	3.420
Permafresh	(B)	85	77	37.1	22.2	3.231
Plain	(C)	86	83	46.4	44.7	3.322
Broadcloth						
Belfast	(A)	142	62	50.3	30.0	4.067
Permafresh	(B)	140	62	47.1	36.1	4.002
Plain	(C)	141	63	76.2	61.4	3.982
Oxford						
Belfast	(A)	94	48	32.5	41.8	3.872
Permafresh	(B)	91	48	29.5	48.1	3.962
Plain	(C)	95	48	48.3	95.7	3.820
Gingham						
Belfast	(A)	89	64	28.6	26.1	3.178
Permafresh	(B)	85	64	31.9	29.6	3.077
Plain	(C)	88	65	47.9	49.7	3.079

C. Elongation Characteristics of Threads

1. Measurement of the extensibility and contraction of the test sewing threads was completed this quarter. The technique of Dorkin and Chamberlain (as described in Technological Report 10 of the Clothing Institute of London), was utilized. Table II shows the results for the four counts each of which was available in eight finishes. It is hoped that these data can be related to other results as the project continues.

2. Dorkin and Chamberlain's technique for testing sewing threads for extensibility and contraction consists of making measurements of a single strand of the thread one meter long against a meter stick. The meter stick is placed in a vertical position with the thread hung from a screwhead so that the thread hangs free in front of the scale on the meter stick. The free end of the thread is tied to a hook weighing about 2 grams. Readings are then made at knots at top and bottom of the thread to determine its actual length under a load of 2 grams. A 100 gram weight is then placed on the hook and readings again taken. The increase in length is then computed as a percentage of the original length under 2 grams load.

3. The thread is removed from the meter stick and boiled for five minutes, allowed to air dry and then replaced on the meter stick with the 2 gram load on the thread. Readings are made and the contraction in length is calculated as a percentage of the original dry length under the 2 gram load. The sum of the percentage of extensibility under 100 gram load and the percentage of contraction after boiling <u>may be</u> an index of the tendency of the thread to produce pucker. About 3% or less seems to be satisfactory, while higher percentages may indicate potential trouble when used with <u>easily puckered</u> materials.

TABLE II

EXTENSION AND CONTRACTION OF SEWING THREAD
BEFORE AND AFTER BOILING

	70/2			80/2			100/2			120-140/2		
	A	B	A + B	A	B	A + B	A	B	A + B	A	B	A + B
Soft White	1.96	1.51	3.47	2.25	1.88	4.13	2.10	1.72	3.82	2.02	1.64	3.66
Soft White Resin A Uncured	1.95	1.09	3.04	2.13	1.19	3.32	2.06	1.01	3.07	1.94	0.84	2.78
Soft White Resin A	1.92	1.71	3.63	1.96	1.73	3.69	1.99	1.15	3.14	2.01	1.31	3.32
Soft White Resin B Uncured	1.83	1.61	3.44	2.04	1.62	3.66	1.90	1.33	3.23	2.09	1.24	3.33
Soft White Resin B	1.78	1.50	3.28	1.91	1.89	3.80	1.72	1.57	3.29	1.83	1.56	3.39
Mercerized White	1.34	1.38	2.72	1.42	1.36	2.78	1.16	0.97	2.13	1.30	0.95	2.25
Mercerized White Resin A	1.11	1.11	2.22	1.26	1.19	2.45	1.09	0.81	1.90	1.30	0.83	2.13
Mercerized White Resin B.	1.10	1.45	2.55	1.24	1.55	2.79	1.03	1.16	2.19	1.20	1.03	2.23

(A) Extension under 100 gr. load (%) $= \dfrac{\text{Length under load - Length under hook}}{\text{Length under hook}} \times 100$

(B) Contraction in boiling water (%) $= \dfrac{\text{Length under hook - length after boil}}{\text{Length under hook}} \times 100$

D. Sewing

Test sewing of print cloth without wash-wear treatment (Finish C) being seamed with thread that has not been wash-wear treated either was started during the 3rd Quarter. A Union Special lockstitch sewing machine type 61400 was used. Two of the test cycles to be sewed on this machine were conducted. These cycles are for single needle operation on print cloth. They will be followed by the same cycles on double needle operations on print cloth. (Each cycle consists of two periods. During the first period the sewing is done. The sample is then evaluated by visual inspection. Two methods of visual inspection are used: first a general statement by the inspector that the sample "appears acceptable or unacceptable without reference to any standard but his judgment". This is followed by a comparison of the sample with test seams from AATCC Test 88B and a rating against those seams. The sample is then measured photometrically and a photomicrograph made. In the second period the sample is laundered in accordance with provision of AATCC Standard 88B, let drip until dry, and re-examined. A photomicrograph is then made of the condition of the sample after laundering.)

E. Photomicrography

Photomicrography holds definite promise as a means of permanently recording the initial appearance of each sample after sewing and prior to laundering. Samples will be photographed again after laundering. The equipment now used for this work is a Bausch & Lomb "L" Camera using a 4 x 5 plate at a power of approximately 1x. Enlargement of the resultant image to about 2x was done during printing.

F. Supplies and Equipment

1. The four fabrics which were received in late December 1964 have been physically characterized. The results of this study are shown in Table I of this report.

2. The four sizes of sewing thread were also received in late December 1964 from Coats and Clark Research Laboratory. No physical analysis has been made of these threads but they have been carefully catalogued by type of finish. The sizes are 70/2, 80/2, 100/2, and 120/2 in both soft and mercerized finish. Each finish in turn consists of three portions, i.e. untreated; treated with dimethylethylurea (DMEU) and cured; treated with DMEU but left uncured, treated with triazine and cured; treated with triazine but left uncured.

3. Union Special Machine Company provided a single needle lockstitch machine complete with table, stand and motor for use on this project.

4. Technological Report 12 (Part II on the Problem of Shrinkage) was received from the Clothing Institute (London).

G. Conferences

Dr. Guenther, Chief of Chemical Section of Coats and Clark Research Laboratory, conferred with the staff of this project on January 26, 1965. He offered many suggestions on sewing techniques for the special test threads prepared by that laboratory for this project.

III. CONCLUSIONS AND FUTURE PLANS

Photometric measurement of seam pucker shows considerable promise. It should reach the practical stage during the 4th Quarter after further work to find the optimum angle for the reflected light.

The physical characteristics of the test fabrics and threads appear to be satisfactory for the work specified in the contract.

Work on the evaluation of print cloth should be completed during the 4th Quarter.

Further work should be done to clarify the relationship between observed curves for a seam and its tendency to pucker, either upon sewing or later after washing.

QUARTERLY REPORT 4

PROJECT A-786

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QUARTERLY REPORT 4

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ABSTRACT

Emphasis was placed on study of the basic physics of seam pucker during this quarter. An attempt was made to determine whether the surface characteristics of the treated threads and fabrics differed from their untreated versions. Enough variation was found among the fabrics to warrant further study. Although the treated and untreated threads appeared to be similar, sewability tests showed major differences among the threads. When standard sewing techniques used for untreated fabric were tried with treated fabrics, sewability decreased greatly.

Study of seams before and after laundering confirmed that warp seams puckered most. These data correlated with results of boiling water immersion tests and earlier work on the elongation or shrinkage of the test threads. There was a major difference between the dimensional changes in the fabrics and in the threads. This would be a partial explanation of some puckering.

Another aspect studied indicates that manufacturing pucker induced by the operator is intensified by laundering. Conversely, there is little evidence that laundering caused severe puckering but rather increased puckering already present.

Study of the surface characteristics of the fabrics included needle penetration areas, fabric geometry and the nature of the deformation caused by the needle. It appears that needle damage to the yarn systems is unlikely except for the filling yarns of oxford cloth. Resin treatments tend to stabilize the fabric structure. Therefore it was assumed that needle damage would be worse in the treated fabric. So far this assumption has not been proved.

Further study on many aspects of the basic physics will continue during the next quarter. It is planned to use two research teams, one studying the

basic physics of seam pucker while the other will attempt to optimize commercial sewing techniques. The photoelectric measuring device will be used extensively in these studies. It is planned to complete all single needle sewing on print cloth during this period.

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I. INTRODUCTION

During the past quarter a review was made of conditions in sewing as they existed before the introduction of wash wear treatments. By reconstructing these conditions it was possible to observe the nature and degree of puckering formerly experienced in sewing. This study will serve as a reference point for subsequent studies of the changes which industry has faced as various minimum care treatments were introduced.

Because the basic physics of seam pucker can be studied best through the examination of the interrelation of threads and yarns, emphasis was placed on this phase of the research. Starting with untreated fabrics and threads, each type of treatment was studied in an effort to determine its contribution to puckering. Small segments of various seams were studied in detail to determine the effect of various treatments on sewability, needle damage and surface characteristics of the test threads and fabrics.

II. EXPERIMENTAL WORK

A. Investigation of Sewing Conditions before Introduction of Wash Wear Treatments

A test cycle was conducted using untreated print cloth in which seams were sewed with 70/2 soft untreated thread under varying conditions. The seams were sewed in warp, filling and bias directions. Two samples were sewed for each variation. Both flat and French seams were sewed. Stitch length was varied in two stitch increments from 10 through 16 stitches per inch (SPI).

A second test cycle was conducted identical to the first cycle except that 00/2 mercerized finish untreated thread equivalent to 70/2 soft finish was used and sewing at 10 SPI was omitted.

Upon completion of the two cycles the appearance of each sample was evaluated in accordance with the provisions of the overhead evaluation procedure in AATCC Method 88B. An attempt was made to predict puckering by comparison between the samples before washing and the standards after washing. The appearance of the seams in each sample was rated by three observers making independent observations.

The results of the observations were then correlated. Samples which showed low correlation of ratings assigned by the three observers were set aside for further study. The remaining samples were subdivided for further study. At first one sample from each variation group was set aside. This yielded too many samples for detailed study so a further division was made by stitch length and only the 12 and 16 stitches per inch samples were retained. (This decision was based on the trade practice of using 12 SPI for concealed seams and 16 SPI for visible seams.) Twelve samples from

70/2 soft group were chosen for detailed study while 13 were chosen from the 00/2 mercerized group.

These 25 samples were laundered in accordance with Washing Procedure I and Drying Procedure A of AATCC Method 88A. The cycle was repeated five times. The reasoning used in allowing the samples to drip-dry was that this duplicated the distinctive technique originally recommended for wash wear treated fabrics. Therefore the appearance of an untreated fabric after wash wear cycle laundering could be used as a reference point for comparison with the results of identical launderings of wash wear treated fabrics.

The laundered samples were reinspected and evaluated by the same three inspectors. In addition to the visual inspections made before and after laundering, the samples were examined photometrically. Tracings were made of selected segments of the seams on each sample, both before and after laundering.

Photomicrographs were made of the selected segments before and after laundering. Each photomicrograph was examined and an adjective rating assigned based on the degree of puckering observed.

Tables 1 and 2 show the results of this study.

B. Characteristics of Sewing Threads after Sewing

The effect of sewing on a known length of untreated thread was also studied. Both 70/2 soft and 00/2 mercerized thread were used. A 90 cm length of the thread was sewed at full speed and 12 SPI into untreated print cloth to form one warpwise seam. Five identical seams were then sewed parallel to the first and spaced $1\frac{1}{2}$ inches apart. The procedure was repeated on Belfast and Permafresh print cloths. Eighteen seams were sewed with 70/2 and eighteen seams with 00/2 thread.

TABLE 1

SEWING UNTREATED PRINT CLOTH WITH 70/2 SOFT FINISH UNTREATED THREAD

Seam Type and Stitches/Inch	Rating before Laundering	Rating after Laundering	Degree of Puckering Shown in Photos after Laundering
12 SPI			
Flat Warp Single	2	1	Severe
Flat Filling Single	2	2	Moderate
Flat Bias Single	5	4	Slight
French Warp Single	2	1	Severe
French Filling Single	3	3	Slight
French Bias Single	5	4	Slight
16 SPI			
Flat Warp Single	1	1	Severe
Flat Filling Single	2	2	Slight
Flat Bias Single	4	4	Moderate
French Warp Single	2	1	Severe
French Filling Single	3	2	Moderate
French Bias Single	4	3	Slight

TABLE 2

SEWING UNTREATED PRINT CLOTH WITH 00/2 MERCERIZED UNTREATED THREAD

Seam Type and Stitches/Inch	Rating before Laundering	Rating after Laundering	Degree of Puckering Shown in Photos after Laundering
12 SPI			
Flat Warp Single	2	1	Severe
Flat Filling Single	4	3	Moderate
Flat Bias Single	4	4	Moderate
French Warp Single	3	2	Severe
French Filling Single	4	3	Moderate
French Bias Single	4	4	Slight
16 SPI			
Flat Warp Single	2	1	Severe
Flat Filling Single	3	3	Slight
Flat Bias Single	4	4	Slight
French Warp Single	3	2	Severe
French Filling Single	4	3	Slight
French Bias Single	4	4	Slight

The number of stitches formed by each 90 cm. of thread was counted and the mean computed for each type of fabric and thread. The threads were then carefully picked out, straightened under the minimum load of 1.77 grams and measured. Table 3 shows the results of this analysis. The elongation of the 70/2 soft thread was uniformly less than the comparable 00/2 mercerized thread when sewed into the same fabric. The percentage of elongation of the soft thread remained relatively constant for all three fabric finishes, but the percentage of elongation of the mercerized thread varied widely. The highest amount was noted when sewing untreated print cloth. More stitches were made in the same fabric with mercerized thread. All seam pucker disappeared after the thread was withdrawn, but the treated fabrics lost their pucker more quickly.

C. Determination of the Likelihood of Needle Damage in Sewing Print Cloth

A study was also made to determine whether the addition of wash wear treatment to a print cloth increased the likelihood of needle damage to the yarns during sewing. Using untreated print cloth, two flat seams were sewed parallel to each other and $1\frac{1}{2}$ inches apart, in the warpwise direction using 70/2 soft finish untreated thread. Sewing was at full speed and 12 SPI. Similar samples were prepared using Belfast and Permafresh print cloths and untreated, Belfast and Permafresh oxford cloths.

Each seam was inspected with a 50 power stereomicroscope. The thread was then removed and the area around 100 needle holes reexamined under the microscope. In each case a study was made to determine whether the needle had passed through the interstice or had penetrated either yarn system. A comparison was then made of the density of the weaves and the actual needle damage that had been noted. Table 4 gives the results of this study.

TABLE 3

RELATIONSHIP OF STITCHES TO THREAD LENGTH AFTER SEWING

	70/2 Soft Untreated Thread						00/2 Mercerized Untreated Thread					
Sample #	Number of Stitches			Thread Length after Sewing (cm.)			Number of Stitches			Thread Length after Sewing (cm.)		
	APC	BPC	CPC	APC	BPC	CPC	APC	BPC	CPC	APC	BPC	CPC
1.	393	380	386	94.8	93.9	93.1	391	382	407	94.5	95.5	101.0
2.	385	381	386	94.4	94.0	94.0	394	375	392	96.6	93.2	95.3
3.	379	381	384	93.6	94.1	93.9	391	380	392	95.8	94.0	93.4
4.	379	378	385	93.5	94.1	93.3	392	392	394	96.0	96.4	95.4
5.	382	379	388	93.1	94.3	94.3	395	391	404	96.6	96.5	99.8
6.	387	377	385	93.8	95.6	94.1	387	384	401	95.6	95.6	99.3
Mean	385	379	386	93.9	94.3	93.8	392	384	398	95.9	92.5	97.4
	% Stretch			4.33	4.78	4.22				6.56	5.78	8.22

Original length of thread was 90 cm.
Stitches per inch was 12
APC Belfast print cloth.
BPC Permafresh print cloth.
CPC Untreated print cloth.

TABLE 4

PENETRATION OF YARN SYSTEMS DURING SEWING
OF PRINT CLOTH AND OXFORD CLOTH

Type of Cloth and Finish	Location of Penetration: Through Interstice	Through Warp	Through Fill	Total	Construction: e/in	p/in
Belfast Print Cloth	85	6	9	100	87	78
Permafresh Print Cloth	95	1	5	101	85	77
Untreated Print Cloth	83	7	11	101	86	83
Belfast Oxford	50	10	40	100	94	48
Permafresh Oxford	55	9	37	101	91	48
Untreated Oxford	47	7	47	101	95	48

D. Examination of the Penetration Areas in a Seam

A study was made with a 50 power stereomicroscope of the samples described in Paragraph IIIC. The object of this study was to determine the nature of the deformation which occurs in the yarn systems upon the insertion of a threaded needle. Other studies indicated that the yarns directly under the needle move aside as it approaches. The movement is away from the stress. Simultaneously, a deformation of the opposite system of yarns also occurs. Part of this deformation is attributable to the approach of the needle and part to the frictional contact between the yarn systems.

It was noted that the amount of movement of the yarns was greater in the untreated fabric than in the treated fabric. The holes created in the treated fabric tended to be smaller and closer around the thread than those made in the untreated fabric. There was markedly more deformation of the yarns in the untreated fabric.

E. The Effect of Wash Wear Treatments on Sewability

The sewability of untreated, Belfast and Permafresh print cloths when sewed with untreated and treated threads was also studied. Initially, a seam of balanced stitches was sewed into untreated print cloth using 70/2 soft untreated thread. Then, without changing the tensions or machine settings, additional seams were sewed parallel to the first seam using various wash wear treated threads. The sewing was repeated on Belfast and Permafresh print cloths. The thread was changed to 00/2 mercerized thread and the entire cycle repeated for each variation of that size. All threads were sewed into two plies of the fabric in the warpwise direction to form flat seams at 12 SPI. Sewing was at full speed initially for 21 inches without thread breaks. When it became impossible to sew without thread breaks, the location of each break was marked on the fabric, the needle was rethreaded and sewing continued from the point of the break. When it became impossible to sew at full speed for even a few inches, the machine was slowed to the speed at which a balanced stitch could be formed. In some cases this required turning the machine with the hand wheel. Table 5 gives results of this study.

The resulting seams were examined under a 50 power stereomicroscope. Segments of each seam were selected for further study and stained with blue ink to provide contrast. Photomicrographs were made of the stained sections.

It was observed that untreated threads sewed Belfast and Permafresh treated fabrics as well as they did the untreated fabric. The best results in sewing Belfast and Permafresh print cloth with treated thread were obtained with mercerized thread containing cured triazine treatment. The soft

TABLE 5

SEWABILITY OF VARIOUS THREADS
WHEN USED TO SEW TREATED AND UNTREATED FABRICS

Fabric	Thread	Sewing Speed	Breakage during Sewing
Belfast	soft, untreated	slow and full	no break
Belfast	soft, DMEU uncured	slow	break
Belfast	soft, triazine uncured	slow	break (severe)
Belfast	soft, DMEU cured	very slow	break (severe)
Belfast	soft, triazine cured	slow	break
Belfast	mercerized untreated	slow and full	no break
Belfast	mercer. DMEU cured	slow	break
Belfast	mercer. triazine cured	slow and full	no break
Permafresh	soft, untreated	slow and full	no break
Permafresh	soft, DMEU uncured	very slow	break (severe)
Permafresh	soft, triazine uncured	slow	break (severe)
Permafresh	soft, DMEU cured	slow	break (severe)
Permafresh	soft, triazine cured	slow	break
Permafresh	mercer. untreated	slow and full	no break
Permafresh	mercer. DMEU cured	very slow	break (severe)
Permafresh	mercer. triazine cured	slow and full	no break
Untreated	soft, untreated	slow and full	no break
Untreated	soft, DMEU uncured	very slow	break (severe)
Untreated	soft, triazine uncured	slow	break
Untreated	soft, DMEU cured	very slow	break
Untreated	soft, triazine cured	slow	break
Untreated	mercer. untreated	slow and full	no break
Untreated	mercer. DMEU cured	very slow	break (severe)
Untreated	mercer. triazine	slow and full	no break

thread with this treatment sewed badly on Belfast and Permafresh print cloth. The DMEU treated threads did not sew well at all.

F. Examination of the Surface Characteristics of the Test Threads

Using a seriplane, sample lengths of 70/2, 80/2, 100/2 and 120-140/2 mercerized and soft finish untreated threads were prepared and photomicrographs made of each sample. Using the same technique, samples were prepared of each of the treated threads as follows:

Soft Finish-DMEU uncured and cured treatments

Soft Finish-triazine uncured and cured treatments

Mercerized-DMEU cured treatment

Mercerized-triazine cured treatment

The samples of the same thread size and finish were compared in an effort to detect differences in the surface characteristics. No appreciable difference was observed among the threads.

G. Examination of the Surface Characteristics of the Test Fabrics

Areas were selected at random on each of the 12 test fabrics. Photomicrographs were made of each area for study to determine whether there was any difference in the surface characteristics of the different fabrics before and after wash wear treatment. The following observations were made:

(1) Wash wear treatment appears to have laid most of the fuzz on the yarns compared to the appearance of the untreated fabric.

(2) Belfast fabrics appear to have smaller interstices than Permafresh fabrics. Both of the treated fabrics appear to have smaller interstices than the corresponding untreated fabrics.

(3) Wash wear treatments appear to provide a "clearer" surface, i.e., the fabric makes a more attractive appearance.

(4) Wherever thick places in both systems of yarns meet, a much smaller than normal interstice is formed. The amount of unevenness, therefore, appears to increase the possibility of needle damage.

III. DISCUSSION

The test cycles on untreated print cloth began with the sewing machine set to sew a balanced stitch at full speed. Theoretically, these settings and tension should have produced a seam without puckering. The sewing machine operator was cautioned to avoid manipulation of the samples. Despite these precautions general puckering occurred in each of the untreated print cloth samples. This was accounted for as having been caused by operator manipulation of the fabrics.

Upon laundering the samples using the wash-wear cycle, the puckering was intensified. Laundering also caused considerable wrinkling which tended to mask the severity of the puckering. Neither puckering nor wrinkling was appreciably reduced by drip drying.

Using another group of samples, it was found that the untreated print cloth again showed general puckering after sewing. Localized puckering was not present. In contrast, when the same settings, tensions and sewing technique were used to sew treated fabric, severe localized puckering occurred, but general puckering did not occur.

The response of untreated and treated print cloths to the force of the needle was also studied. The same machine settings, tensions and sewing technique were used throughout so it would appear that the same force was being exerted on all samples. Their deformation as a result of the stress which occurred in the yarn systems should be related to the stability of the weave. The amount of deformation which occurred in the untreated fabric was greater than that which occurred in the treated fabric. The yarns in the immediate vicinity of the needle appeared to absorb the entire force with relatively little deformation. This same force on the yarns of the untreated fabric caused them to deform at a much greater distance from the needle. As a result the same force was distributed or dissipated over a much wider area in the untreated fabric. Conversely, the stress on the treated fabric was concentrated in relatively few yarns.

Upon withdrawal of the needle and thread the treated fabric recovered at a more rapid rate than the untreated fabric did. The needle holes closed and puckering disappeared completely in the treated samples in a much shorter time than with untreated samples. This was expected from the study made of the relative extent of the deformation of both types of print cloth.

Needle damage to the yarn systems was found to be insignificant except in the case of the filling yarns of the oxford cloth which were penetrated frequently. An examination of the holes themselves indicated that those made at low speed showed less deformation of the area immediately surrounding them than those made at high speed. This can be explained in terms of the relative tensions on the threads at different speeds. It appears that a balanced stitch, properly located between the plies, will produce an interlock without puckering either ply. The interlock point moves upward as the tension on the thread increases until the tensions on the needle and bobbin thread again balance. This seems to be a cause of puckering on the needle side of the plies.

The marked difference in sewability among the untreated and treated threads cannot be explained by observations of their surface characteristics.

After elongation during sewing the 70/2 soft untreated thread recovered quicker than the equivalent size 00/2 mercerized thread. During sewing the mercerized thread elongated further, and more stitches were formed from a 90 cm. length than with soft thread. Mercerization may have reduced the elasticity of the thread so that it recovered slower after the straightening load was removed than the soft finish thread did.

Treatment of the fabrics did not appear to affect their sewing with untreated threads. It was possible to sew both Belfast and Permafresh print cloth without thread breaks using untreated threads.

The treated threads did not sew well with the tensions, settings and technique used during the other studies. Only mercerized thread with a cured triazine treatment gave satisfactory performance under these conditions. All other treated test threads broke frequently with greatly reduced sewability.

Study of the changes in sewing technique necessary to achieve excellent sewability will be undertaken. It is planned to attempt to explain the reason why each modification of regular practice is made in terms of its effect on improved sewability.

IV. CONCLUSIONS

General or area puckering occurred when untreated fabrics were sewed with untreated threads. This type of puckering contrasted with the localized puckering which occurred when the same settings were used to sew wash wear treated fabrics. The wash wear treatments did not appear to alter the surface characteristics of the fabrics or threads. A decrease in the size of the interstices did occur, but the likelihood of needle penetration increasing was not established. Therefore, it was concluded that the stabilization of the yarn systems by the wash wear treatment was not sufficient to inhibit the movement of the yarns clear of the needle during sewing. It appeared that the treatment did change the ability of the fabric to deform under stress. Less deformation was likely to occur when the fabric had been wash-wear treated. Upon release of the stress imposed by the presence of the thread, the treated fabric was able to recover quicker than the untreated fabric. This indicated greater dimensional stability.

V. FUTURE PLANS

Study of each of the areas in this report will be continued during the next quarter. Two teams will be employed, one to examine the variations in sewing technique required to accommmodate fabrics with minimum care treatments and the other to study the basic physics involved in seam puckering.

The sewing technique team will attempt to isolate each factor which contributes to seam pucker. Then by varying that factor, its effect on the other factors will be studied and optimized. Sewing on print cloth should be completed during the coming quarter.

A major part of the study planned for the quarter will be on the characteristics of the treated test threads. These threads are not in commercial production so the research on them has to be closely coordinated with the Coats and Clark Research Laboratory staff. This has been done by quarterly visits of a representative of their staff to the campus. In addition, the laboratory has undertaken work on these threads which will supplement the efforts on campus.

The attempt to treat the thread as a beam and the cloth as a flat surface, both of which are subject to the laws of physics, has progressed well. The use of Applied Mechanics techniques to explain what is observed seems fruitful.

The photoelectric measuring instrument continues to work well. Further refinements in its design to provide a method of reading qualitative results are underway. If these can be accomplished, it may be possible to use this technique to measure acceptability of seams during final inspection in an apparel factory.

QUARTERLY REPORT 5

PROJECT A-786

PHYSICS OF SEAM PUCKER

JAMES L. TAYLOR and FRANK J. CLARKE

Contract 12-14-100-7193(72)

15 JUNE 1965 to 14 SEPTEMBER 1965

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Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

GEORGIA INSTITUTE OF TECHNOLOGY
A. French Textile School
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SOUTHERN UTILIZATION RESEARCH AND DEVELOPMENT DIVISION
NEW ORLEANS, LOUISIANA

ABSTRACT

Various sizes of resin treated threads in both uncured and cured form were evaluated. None of the treated threads met commercial sewability standards. There was a loss in strength between the untreated and treated versions of the same thread. Other factors may also contribute to the decrease in sewability, but physical examination of the threads failed to isolate them. Further study of the nature of the change in the threads upon treatment is planned. Other experimental threads using the Koratron process or cotton cabling on synthetic fiber cores will be evaluated.

Analysis of the AATCC Test Method 88B rating system indicated that the interval between classes was not constant. The standards were not descriptive of many samples which fell between two discrete ratings. Four additional classes were established to describe these samples. The expanded rating system provided high correlation between ratings assigned to samples by visual inspection and by the photometric device. These findings tended to confirm earlier empirical work on the effect of machine speed, stitch length, sewing direction, etc. on seam pucker. Pucker resulting from both yarn jamming and the use of incompatible threads and fabrics was studied. Formulas were derived to minimize yarn jamming.

Mathematical analyses of the curves resulting from scanning samples with the photometric devices indicated the nature of the variation in the amplitude and frequency of pucker. Samples which were classified 1 and 2 showed sever puckering characterized by high amplitude and short cycle. Samples rated 3 showed smaller puckers further apart than classes 1 and 2.

Classes 4 and 5 were difficult to separate. The amplitude of the pucker was low and the cycles were long. The distortion inherent in the background fabric allowed this puckering to blend in it, making it difficult to detect even on a white fabric. Class 3 samples were rated acceptable in some cases. The high incidence of this class indicated the probability that products of this rating could be produced consistently in commercial sewing.

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I. INTRODUCTION

The last quarterly report included a description of test cycles on untreated print cloth sewed with untreated thread. These cycles were intended to provide a starting point to compare the changes in intensity of puckering which occurred after wash-wear treated fabrics were introduced. This quarter the study was extended to include the sewing of wash-wear treated fabrics with wash-wear treated threads. Both uncured and cured resin treated threads were evaluated. None of these threads produced a satisfactory stitch at sustained commercial sewing speeds without breaking.

Upon completion of the study at Georgia Tech the treated threads, which had been prepared by Coats and Clark Laboratory, were re-examined by that company. The re-examination included sewability, breaking strength and thread count determination. Their findings confirmed the work done at Georgia Tech. None of these treated threads was suitable for commercial sewing. The condition of the threads precluded evaluation of them as a means of minimizing seam pucker. Further study of these treated threads is planned in an effort to determine what changes had occurred that reduced their sewability.

This quarter 876 samples of test fabric were sewed and evaluated. Both the visual rating method prescribed in AATCC Method 88B and the photometric method described on page 2 of Quarterly Report 3 were used. From these evaluations a series of typical curves to describe pucker were developed. These curves indicated that the five discrete rating classes used in the AATCC rating system may be inadequate to describe pucker. An interim grouping of nine rating classes was developed to more accurately describe the conditions likely to be encountered when measuring seam pucker.

From this work it appeared that a midrange existed in the occurrence of pucker. In this midrange pucker was present but still acceptable to consumers. This midrange appeared to require less exacting work than that demanded for the absolute minimization of seam pucker. It seemed probable that this level could be attained consistently by the average operator using commercial sewing techniques. Work during the next quarter will seek to measure this midpoint using the photometric device as a quality control tool.

Work was done concurrently on the basic physics of seam pucker as it relates to the selection of thread size, needle size, thread tension, sewing direction, type of seam and stitches per inch.

The stereomicroscope was utilized for a study of the formation of a single stitch. This research showed that there was an inherent tendency to pucker whenever the number of stitches sewed per inch caused yarn jamming. This first type of puckering was intensified when the thread size exceeded the optimum for the cloth construction being sewed. This concept was explained mathematically through the use of three formulas which provided the means of reducing this type of pucker.

A second type of inherent pucker resulting from the selection of incompatible threads and fabrics will be studied further.

No difficulties were encountered in sewing treated fabrics with various sizes of either soft or mercerized untreated thread using the sewing technique and conditions used for untreated fabrics. Washing appeared to make only minimal changes in the counts of the thread.

II. EXPERIMENTAL WORK

A. Sewing Procedure

1. Investigation of conditions and techniques for sewing untreated and treated fabrics.

a. During the previous quarter the conditions and technique for sewing untreated print cloth with untreated ticket number 70/2 soft and 00/2 mercerized finish thread were studied. Both flat and French seams were sewed in the warp, filling and bias directions with stitch lengths varied in two stitch increments from 10 through 16 stitches per inch. The results of this study were included in the Quarterly Report dated June 12, 1965.

These conditions and technique used to sew untreated print cloth were carefully noted so that they could be reproduced as a beginning point for sewing other fabrics and threads. One objective of this study was to determine whether changes in conditions and technique were required to optimize sewing of other fabrics and threads.

This quarter the same conditions and technique were used to sew samples of untreated print cloth with ticket 80/2, 100/2 and 120-140/2 soft and mercerized untreated threads.

The original conditions and technique were also used to sew samples of Belfast and Permafresh print cloth using 70/2, 80/2, 100/2 and 120-140/2 soft and mercerized untreated thread.

These cycles produced sufficient samples for evaluation of the results of sewing untreated and treated print cloth with four sizes of both soft and mercerized untreated thread. This completed the single needle sewing of untreated and treated print cloth.

b. The large number of samples of untreated and treated print cloth sewed with each ticket size of soft and mercerized untreated thread required further segregation of samples before detailed evaluation could be made. Samples from each lot sewed at 12 stitches per inch (SPI) and 16 SPI were chosen for further study.

2. <u>Effect of resin treatments on thread sewability</u>.

a. Tests made during the past year determined that wash wear treated threads would not sew satisfactorily when the standard conditions and techniques for sewing untreated thread were used. This study was continued to determine whether treated threads would sew satisfactorily under other conditions.

A test was run to find the optimum conditions for sewing a balanced stitch at maximum speed using treated thread. The machine was threaded with 70/2 soft untreated thread and adjusted until a balanced stitch was made at 12 SPI on 21 3/4" x 21 3/4" samples of Belfast broad cloth. The machine was rethreaded with 70/2 soft DMEU uncured thread in both bobbin and needle and sewing continued.

Initially, thread breakage occurred in the needle thread frequently. The bobbin tension was held constant and the upper (needle) tension decreased to the point where the least breakage occurred. The upper tension was then held constant and the bobbin tension decreased until a balanced stitch was obtained.

Six seams were sewed with these settings. Each thread break was marked, the needle rethreaded and sewing proceeded.

This procedure was repeated with Permafresh and untreated broad cloth; Belfast, Permafresh and untreated oxford cloth; Belfast, Permafresh and untreated gingham. This completed the evaluation of uncured DMEU treated 70/2 soft finish thread.

Similar tests were made of 70/2 soft DMEU cured, 70/2 soft triazine cured, and 70/2 mercerized triazine cured threads. Table 1 contains the data obtained in these tests.

Earlier research at Georgia Tech had indicated the possibility that triazine treated threads would sew. A continuation of this study using simulated commercial sewing conditions showed excess thread breakage. Although triazine treated thread did sew better than DMEU thread, neither thread was satisfactory.

To preclude the possibility of incorrect machine settings as a cause of poor sewability, a representative of Union Special Machine Company checked the sewing machine used in these tests. He found that the machine was correctly set for a balanced stitch when untreated thread was used; however, it was impossible to use this setting to sew with any of the treated threads at normal production speeds without excessive thread breakage. He determined that there was a point at which a balanced stitch could be made at lower speeds without excessive breakage. This point differed among the fabrics and threads, necessitating a special setting of the machine for each thread and fabric combination. Generally, the needle and bobbin tensions had to be greatly reduced and a careful balance of tensions appeared critical to good stitch formation.

An analysis of this work together with the data contained in Table 1 showed that none of the treated threads tested is acceptable for commercial sewing.

TABLE 1

SEWABILITY OF RESIN TREATED THREAD

Thread Ticket Number and Finish	Fabric Finish	Thread Breaks*		
		Broad Cloth	Oxford	Gingham
70/2 soft DMEU-uncured	Belfast	4	5	4
	Permafresh	1	2	9
	Untreated	4	5	4
70/2 soft DMEU-cured	Belfast	15	17	20
	Permafresh	38	27	36
	Untreated	27	23	20
70/2 mercerized DMEU-cured	Belfast	37	20	24
	Permafresh	25	24	34
	Untreated	19	25	22
80/2 soft Triazine-uncured	Belfast	6	1	1
	Permafresh	5	8	2
	Untreated	5	5	4
80/2 soft Triazine-cured	Belfast	19	11	3
	Permafresh	9	13	3
	Untreated	17	17	10
80/2 mercerized Triazine-cured	Belfast	7	4	5
	Permafresh	8	4	3
	Untreated	8	5	5

* Breaks were calculated per 162 " sewed at 12 SPI using 5000 RPM.

b. A test was made to determine the possibility of correlation between thread breakage and a possible defect in the machine itself. Two plies of Belfast broad cloth 18"x 43" were used. Parallel lines of stitching were sewed 1½" apart in the filling direction using 12 SPI. The stitches were made with 70/2 soft DMEU-uncured thread. The distances between thread breaks were marked and measured. The results were tabulated and analyzed. There was no apparent correlation between thread breaks and possible machine defects. There was no apparent build up of thread tension and wear that caused the thread to break.

3. Analysis of thread by Coats and Clark Laboratory.

As a further check on the sewability of these threads, it was decided to eliminate operator manipulation and machine malfunction by sewing on several automatic machines. Coats and Clark Laboratory, Atlanta, Georgia conducted the tests. It was agreed that sewability would be judged by the ability of the machine to form balanced stitches at commercial speeds over prolonged periods of continuous sewing.

The automatic sewing machine used for the sewability tests was a Singer, model 251-12 with a maximum sewing speed of 4500 RPM. This machine was the nearest equivalent to the Union Special 63400-A machine being used in this project available at the laboratory. A Singer needle, size 14 (equivalent to the Union Special needle size 183GL-036) was used. Sewing was done at 14 SPI. The machine was threaded with the 70/2 soft untreated thread. The tensions were adjusted to give a balanced stitch at maximum sewing speed. The test thread was sewed into four thicknesses of the test fabric to maximize the sewing conditions. After 15 minutes the sewing was stopped and a tensiometer was attached. The tensiometer measured the amount of drag or tension (in grams) that was being applied to the thread by the thread guides and the upper tension regulator. Identical sewability tests were conducted using sixteen cones of test thread. Included were 70/2 and 80/2 soft and mercerized untreated thread, 70/2 and 80/2 soft DMEU-uncured thread, 70/2 and 80/2 soft DMEU-cured thread, 70/2 and 80/2 mercerized DMEU thread, 70/2 and 80/2 soft triazine-uncured thread, 70/2 and 80/2 soft triazine-cured thread, and 70/2 and 80/2 mercerized triazine thread.

Similar sewability tests were run at full speed on a Singer 600 WL machine at 3975 RPM, a Singer 241-1 machine at 3971 RPM, and a Union Special chain-stitch machine at 3725 RPM. No severe thread breakage occurred at these lower sewing speeds.

Physical evaluations of the test threads made at Coats and Clark Laboratory included tension pressure on needle thread during sewing, breaking strength in lbs., percent elongation and equivalent yarn size. An adjective rating of sewability was assigned to each thread.

The results of these tests are shown in Table 2.

B. Microscopy of a stitch.

During the previous quarter a study was made to determine the nature of the deformation which occurs in the yarn system upon the insertion of a threaded needle. This quarter the study was continued by analyzing the deformation in the yarn system caused by the stitch formation. The study was made using 37 test samples from the three sets of single needle sewing test cycles. These samples were selected because they showed greater difference than one grade in visual rating assigned by raters or showed interesting curves produced by the photometric device. These samples were inspected using a 50 power stereomicroscope.

RESULTS OF TESTS MADE BY COATS & CLARK LABORATORY

Thread Ticket Number and Finish	Tension Pressure (grams)	Sewability of Thread	Breaking Strength (lbs.)	Elongation (%)	Measured Size
70/2 soft untreated	300-340	Will sew	1.62	6.6	35.0
00/2 mercerized untreated	290-340	Will sew	1.93	4.8	36.0
80/2 soft untreated	290-320	Will sew	1.45	7.0	40.0
80/2 mercerized untreated	280-320	Will sew	1.63	4.8	40.0
70/2 soft DMEU-uncured	169-190	Will not sew	1.32	5.0	35.0
70/2 mercerized DMEU-cured	200-250	Will not sew	1.27	4.6	35.7
70/2 soft DMEU-cured	x	x	1.20	5.2	36.5
80/2 soft DMEU-uncured	200-220	Will not sew	1.26	5.6	37.7
80/2 soft DMEU-cured	x	x	1.07	4.6	39.0
80/2 mercerized DMEU-cured	x	x	1.32	4.2	39.0

Thread Ticket Number and Finish	Tension Pressure (grams)	Sewability of Thread	Breaking Strength (lbs.)	Elongation (%)	Measured Size
70/2 soft triazine-uncured	x	x	1.32	5.0	36.0
70/2 soft triazine-cured	x	x	1.32	5.0	34.5
70/2 mercerized triazine-cured	x	x	1.72	5.0	35.7
80/2 soft triazine-uncured	160-190	Will not sew	1.17	5.6	40.0
80/2 soft triazine-cured	x	x	0.98	4.2	38.5
80/2 mercerized triazine-cured	x	x	1.64	5.4	38.5

x = Not measured.

Microscopic examination of a stitch showed that the yarns contained in the stitch in some of the samples lay in the same plane before laundering. This study showed that after laundering the yarns contained in a stitch were jammed together between the interlock points of the ends of the stitch. They no longer occupied the same plane, but had been pushed up and down during the sewing and laundering process.

The following technique was used to calculate the length of stitch needed to allow the yarns of a given fabric to remain in the same plane:

1. The space occupied by the yarn and thread systems was determined by measuring the diameter of fifty warp and fifty filling yarns and the diameter of the untreated sewing thread. A toolmaker's microscope with microcaliper was used to make these measurements. They were:

Type of Fabric	Average Diameter of yarns in fabric (mm)
Belfast Print Cloth	0.1826
Permafresh Print Cloth	0.1951
Untreated Print Cloth	0.1897

Thread Ticket Number	Average Diam. (mm) Soft White	Average Diam. (mm) Mercerized White
70/2	0.2611	0.2493
80/2	0.2583	0.2342
100/2	0.2215	0.2268
120-140/2	0.2021	0.1967

2. Density of the yarn (See quarterly report number 3) computed from cloth construction (Warp X Filling).

Cloth	Warp Yarn per inch	Warp Yarn per cm	Filling Yarn per inch	Filling Yarn per cm
Belfast	87	34.25	79	31.10
Permafresh	85	33.46	77	30.31
Untreated	86	33.86	83	32.68

3. Formulas derived were:

a. Theoretical length of a stitch =

$$\frac{1}{\text{Number of stitches/inch or cm}} = \text{inch or cm}$$

b. Space in a stitch occupied by yarns and thread =

Diameter of yarn x number of yarns/inch + 3(Diameter of thread)*

c. Maximum number of stitches that can be accommodated in an inch without jamming =

$$\frac{\text{25.4 mm/inch-number of yarns/inch x diam. of yarn}}{\text{3(Diameter of thread)*}}$$

*In this calculation the interlock of two threads at beginning of stitch is considered as occupying the space of two thread diameters while at the end of the stitch there is only one diameter, the other being counted on the next stitch.

4. Comparison of theoretical stitch length and the maximum number of stitches which could have been accommodated without jamming is show in Table 3.

Table 3 Optimum Stitches Per Inch

Untreated Print Cloth (warpwise)

Number of SPI		10	12	14	16	Max. no. of SPI
Theoretical Length of Stitch		2.54 m/m	2.117 m/m	1.814 m/m	1.588 m/m	
Space occupied by yarns and thread/ stitch	Soft					
	70/2	2.358 m/m	2.095 m/m	1.908*m/m	1.767*m/m	12.3
	80/2	2.349	2.087	1.900*	1.759*	12.5
	100/2	2.239	1.977	1.789	1.649*	14.5
	120-140/2	2.181	1.918	1.731	1.590*	15.9
	Merc.					
	70/2	2.322	2.060	1.873*	1.732*	12.9
	80/2	2.277	2.015	1.827*	1.687*	13.7
	100/2	2.255	1.993	1.805	1.655*	14.2
	120-140/2	2.165	1.902	1.715	1.574	16.4

Belfast Print Cloth (warpwise)

Number of SPI		10	12	14	16	Max. no. of SPI
Theoretical Length of Stitch		2.54 m/m	2.117 m/m	1.814 m/m	1.588 m/m	
Space occupied by yarns and thread/ stitch	Soft					
	70/2	2.226 m/m	1.985 m/m	1.814 m/m	1.685*m/m	14.0
	80/2	2.217	1.977	1.805	1.677*	14.2
	100/2	2.107	1.867	1.695	1.566	16.5
	120-140/2	2.049	1.808	1.637	1.508	18.1
	Merc.					
	70/2	2.190	1.950	1.778	1.650*	14.7
	80/2	2.145	1.905	1.733	1.604*	15.6
	100/2	2.123	1.883	1.711	1.582	16.1

Permafresh Print Cloth (warpwise)

Number of SPI		10	12	14	16	Max. no. of SPI
Theoretical Length of Stitch		2.54 m/m	2.117 m/m	1.814 m/m	1.588 m/m	
Space occupied by yarns and thread/ stitch	Soft					
	70/2	2.286 m/m	2.035 m/m	1.856*m/m	1.722*	13.3
	80/2	2.277	2.027	1.848*	1.714*	13.4
	100/2	2.167	1.916	1.738	1.603*	15.6
	120-140/2	2.109	1.858	1.679	1.545	17.1
	Merc.					
	70/2	2.250	2.000	1.821*	1.687*	13.9
	80/2	2.205	1.955	1.776	1.642*	14.8
	100/2	2.183	1.932	1.754	1.619*	15.3
	120-140/2	2.092	1.842	1.667	1.529	17.6

*Jamming of yarns will cause movement out of common plane.

C. Dimensional stability of test fabrics

As an extension of the study made of the test threads using the technique developed by Dorkin and Chamberlain (see p. 9, Quarterly Report 3) similar tests were made of the four fabrics.

On a sample of each test fabric, three lines were drawn 12" apart in both warp and filling directions. Each sample was immersed in boiling water for five minutes, then dried and conditioned for 24 hours at 70^{o} F (65% humidity). Each sample was then remeasured. The results were recorded in Table 4.

Table 4 Stability of Cloth After Boiling

Treatment on Cloth	Untreated		Belfast		Permafresh	
Direction	warp	filling	warp	filling	warp	filling
Type of Cloth						
Print Cloth	+1.5%	-3.75%	+0.92%	-1.42%	0.0%	-0.75%
Broad Cloth	-2.75	-0.17	-0.75	-0.33	-0.33	-0.17
Oxford	+0.5	-2.25	+0.67	+0.5	0.0	-0.42
Gingham	-1.5	-0.92	-0.25	-0.25	-0.75	-0.08

+ indicates Extension - indicates Contraction

D. Application of mathematical analysis to the data

The objective of this work was to assign values to the photometric curves using the AATCC rating system as standard and the curves as unknowns. By analyzing data taken from the curves a rating number describing the intensity of pucker could be assigned.

The data to be analyzed consisted of a series of curves which were formed by the readings of the photometric device as it scanned the seam being passed beneath it.

A line of least squares was drawn through selected curve tracings. Then using a planometer the area under the curve and against this line was calculated. This was designated Method I.

Method II, the Ratio Method, compared the length of the trace recorded by the photometric device to a straight line measured in the same unit of time. The straight line represented an ideal sample. The mathematical theory for finding the length of a curve is derived from the formula for the area under the curve.

When $A = \int_a^b f(x)\,dx$

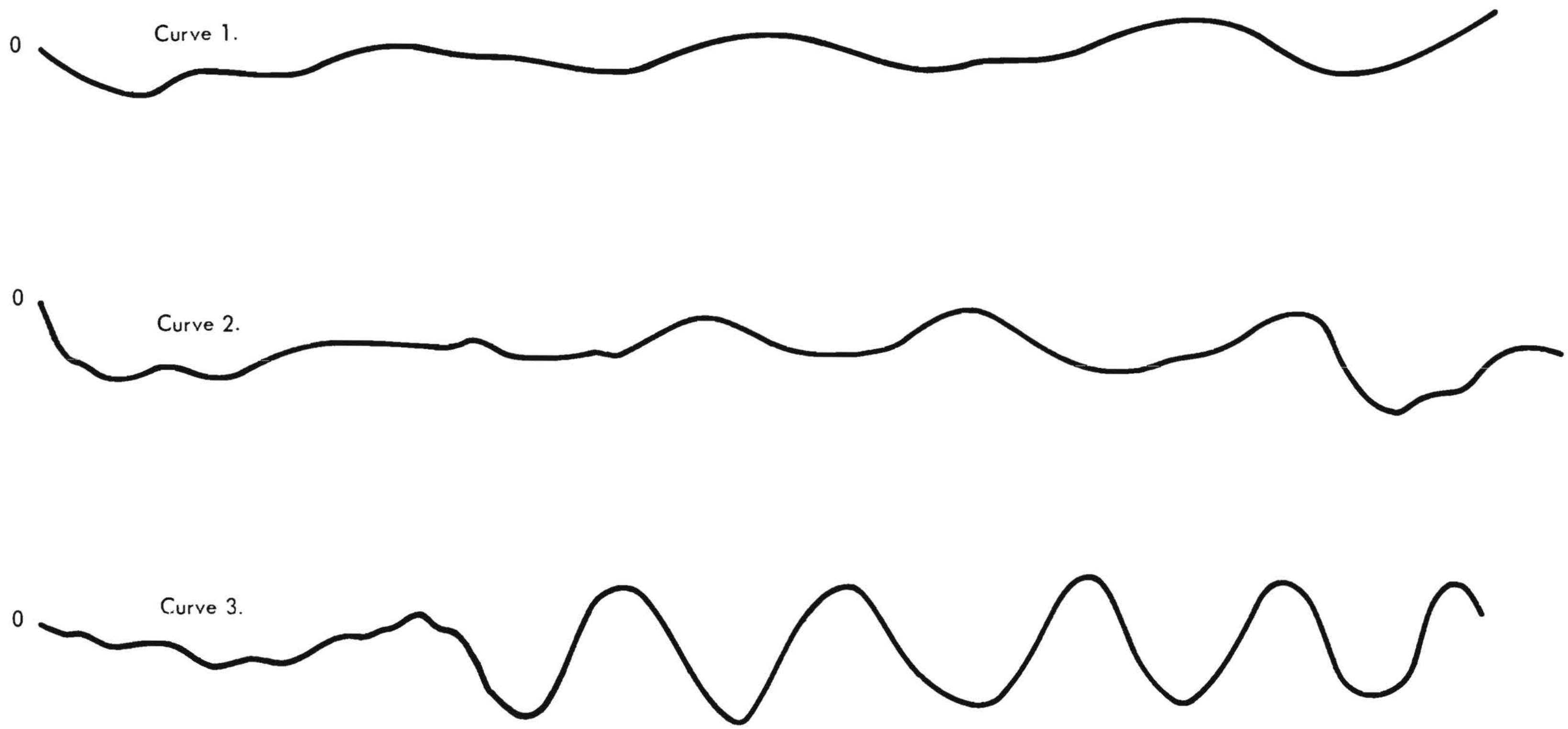
then $L_n = \int_a^b \sqrt{1+x'^2}\,dx$

The term A is the area under the curve expressed by the integral $\int_a^b$ between the limits a and b and dx is a small change in the linear component and x^{1^2} is the square of the first derivative.

An index number was created by using the ratio of the two measurements $\frac{\text{curve}}{\text{straight line}}$.

Using 84 samples, a range of maximum and minimum ratios per Rating Class and an average index were calculated with the following results:

Rating Number	Range	Average Index
1	1.208-1.607	1.382
1-2	1.120-1.377	1.267
2	1.121-1.276	1.193
2-3	1.106-1.343	1.217
3	1.104-1.325	1.165
3-4	1.108-1.173	1.141
4	1.032-1.152	1.085
4-5	1.017-1.096	1.049
5	1.061-1.095	1.064



Graph 1. Typical Tracings.

This method was then applied to all tracings and an analysis of variance was made of the total data. Other statistical tests for validity were then applied to the data with the following results:

AATCC Rating Class	Median	Mean	Std. dev.	Variance	C. V. (%)	5%	1%	Test	Skew.
1	1.478	1.398	0.1325	0.0175	9.5	2.25	3.19	1.73	0.181
1-2	1.324	1.283	0.1004	0.0101	7.8	2.11	2.92	1.94	1.23
2	1.401	1.276	0.1401	0.0196	11.1	1.72	2.17	2.28	2 87
2-3	1.302	1.255	0.0927	0.0086	7.4	1.67	2.08	1.97	1.56
3	1.346	1.227	0.1299	0.0169	10.6	1.91	2.53	1.37	2.75
3-4	1.291	1.208	0.1109	0.0123	9.2	1.74	2.18	2.32	2.24
4	1.203	1.129	0.0729	0.0053	6.5	1.60	1.94	3.60	3.05
4-5	1.216	1.070	0.0392	0.0015	3.7	1.55	1.82	1.67	11.20
5	1.115	1.083	0.0497	0.0025	4.6	X	X	X	1.94

In making the tests F the following relationships were used: class 1 and class 1-2, class 1-2 and class 2, class 2 and class 2-3, class 2-3 and class 3, class 3 and class 3-4, class 3-4 and class 4, class 4 and class 4-5, class 4-5 and class 5.

After calculating the standard deviation, variance, and coefficient of variation, the degree of skewness was calculated by the following formula:

$$\text{Skewness} = \frac{3(\text{mean - median})}{\text{Std. dev.}}$$

To study the data further using the Ratio Method it was necessary to consider the following six variables taken both before and after washing:

Finish on the fabric

Finish on the thread

Size of the thread

Number of stitches per inch

Type of seam

Sewing direction

A computer program for the Burroughs Algol B-220 computer was written to handle these six variables. It was intended to compare the data obtained by the AATCC Visual Rating system and the photometric tracing method. The results of this comparison were recorded in Table 4.

Table 4 A Computer Comparison of the AATCC Visual Rating System and the Photometric Tracing Method

Between Factors	Before Washing: From Rating	Before Washing: From Tracing	After Washing and Drying: From Rating	After Washing and Drying: From Tracing
Finish on cloth	Resin treated> Untreated	Resin treated> Untreated (BPC=APC)	Uncertain	No Sig. Diff.
Finish on thread	Mercerized> Soft	Mercerized> Soft	Mercerized> Soft	No Sig. Diff.
Size of thread	Finer yarn> coarser yarn (100/2> 80/2, 70/2)x1	No Sig. Diff.	Uncertain x2	100/2> 80/2, 70/2
No. of SPI	10 SPI> 12 SPI> 14 SPI> 16 SPI	12 SPI> 16 SPI	Uncertain x3	No Sig. Diff.
Type of seam	French>flat (a little diff.)	Flat> French	French> Flat	French> Flat
Sewing direction	Bias> filling> warp	Bias> filling> warp	bias> filling> warp	bias>filling> warp

x1 A little difference between 70/2 and 80/2
x2 Soft thread: finer yarn> coarser yarn (100/2> 80/2> 70/2)
Merc. thread: coarser> finer (70/2> 80/2> 100/2)
x3 Untreated cloth: High no. of SPI> low no. of SPI (16 SPI> 12 SPI)
Resin treated cloth: Lower no. of SPI> high no. of SPI (12 SPI> 16 SPI)
> Symbol signifying better than, or less puckering

Method III utilized the simple harmonic motion of the sewing machine during sewing. This motion can be described by a series of sine curves with the equation Y = a sine bx.

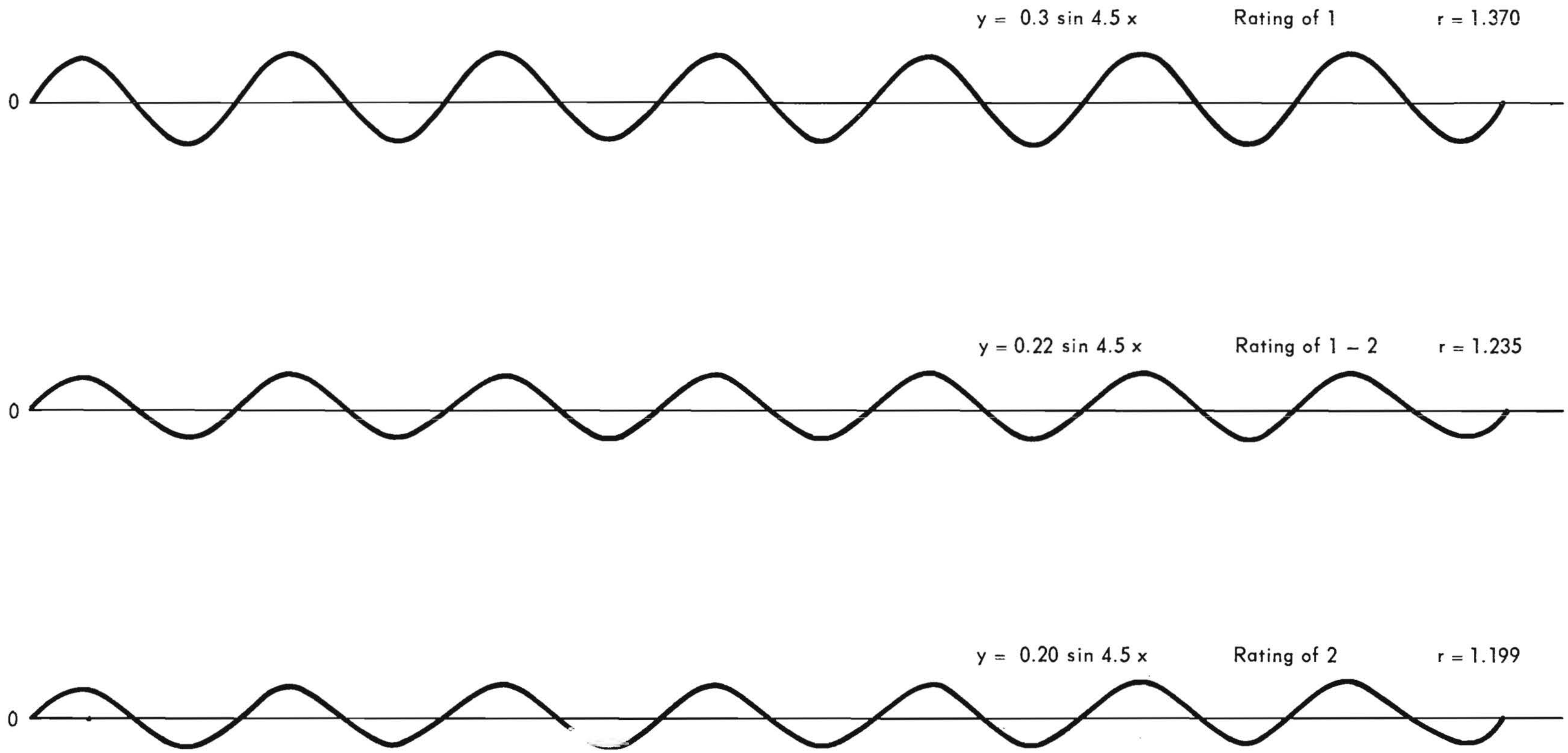
Several measurements were made of the height and length of the cycle. A cycle was defined as the time required for the curve to move from a zero value through all applicable positive and negative values and return to zero. The following data resulted:

Rating Number	Length (cm)	Height (cm)
1	3.5	0.82
1-2	3.4	0.58
2	3.8	0.55
2-3	3.3	0.50
3	3.5	0.30
3-4	4.2	0.37
4	5.7	0.37
4-5	6.2	0.21
5	6.0	0.16

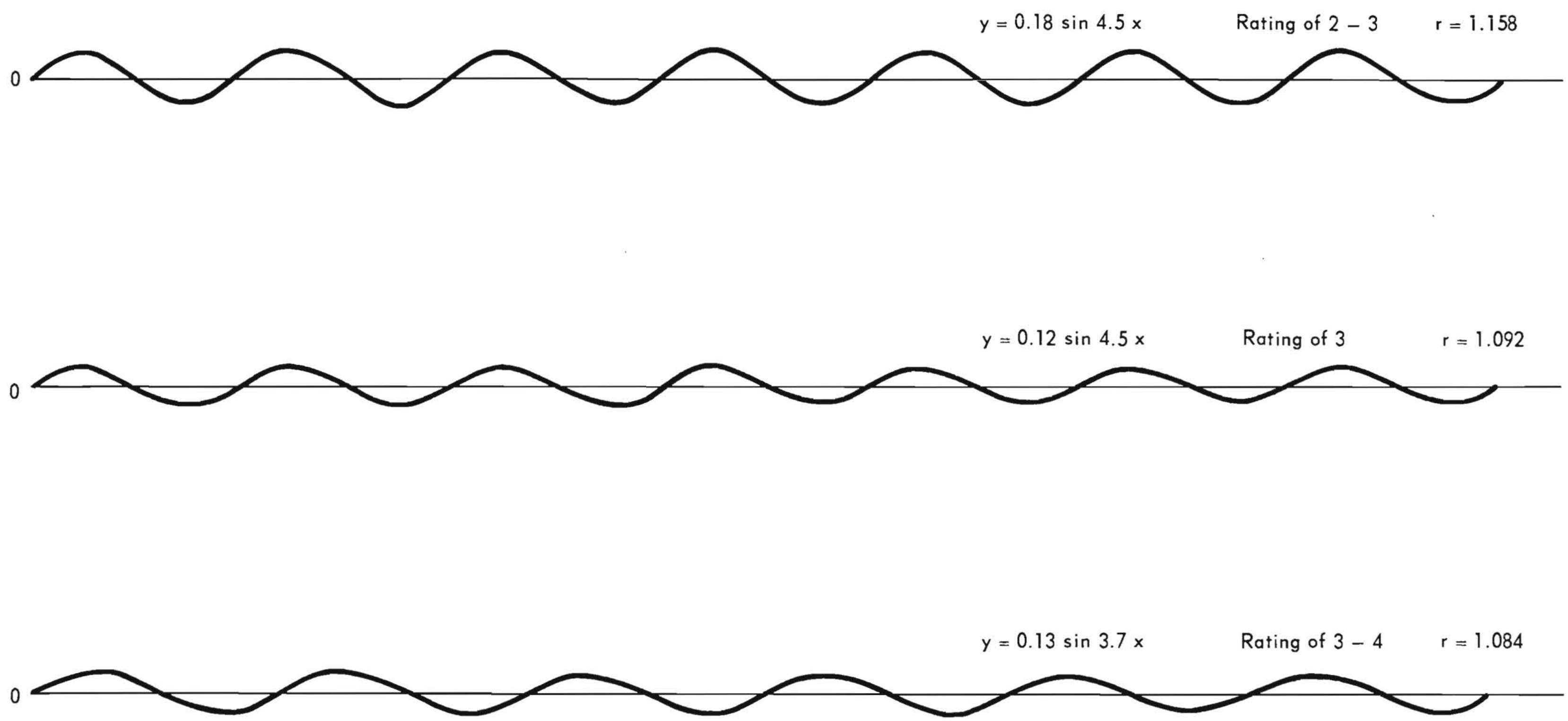
From these data a series of sine curves was constructed (see Graphs 2,3, and 4)

The equations of the sine curves were calculated and Method II (the ratio of the curved line to the straight line) was used to gain information to compare the calculated sine curves with the actual curves from the samples.

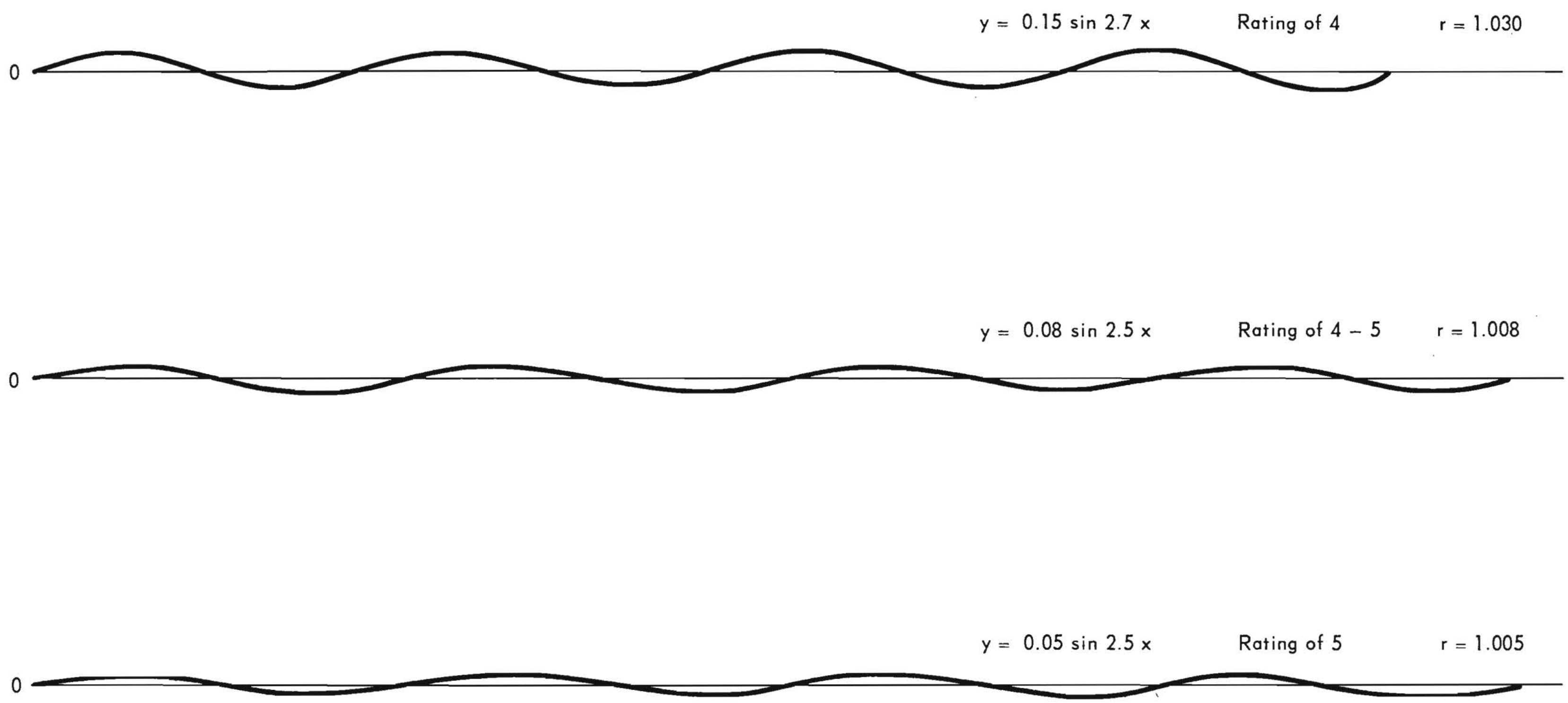
AATCC Rating Class	Equation	Sine Ratio	Actual Ratio
1	y = 0.3 sin 4.5x	1.370	1.382
1-2	y = 0.22 sin 4.5x	1.250	1.267
2	y = 0.20 sin 4.5x	1.195	1.193
2-3	y = 0.18 sin 4.5x	1.155	1.217
3	y = 0.12 sin 4.5x	1.070	1.165
3-4	y = 0.13 sin 3.7x	1.065	1.141
4	y = 0.13 sin 2.7x	1.030	1.085
4-5	y = 0.08 sin 2.5x	1.017	1.049
5	y = 0.05 sin 2.5x	1.012	1.064



Graph 2. Derived Sine Curves.



Graph 3. Derived Sine Curves.



Graph 4. Derived Sine Curves.

III. DISCUSSION

A. Background on commercial sewing practices

1. The choice of fabric is usually restricted in commerical sewing plants to those supplied by the contractor or likely to be readily saleable after an item is sewed from them.

2. The choice of threads is often up to the superintendent or engineer based on his experience, price, availability, strength, operators preference, etc. It is seldom based on a study of the construction of the fabric to be sewed and its finish. Generally, the sewing plant uses as few different ticket numbers and finishes of thread as possible.

3. The choice of the number of stitches per inch and the seam type is a combination of the designers' ideas and the economics of production. Usually a plant has a standard number of stitches per inch for each seam, visible or concealed, etc. This may bear no relation to the direction of the seam on the cloth.

4. The machines are set to sew a balanced stitch on the fabrics and threads in general use. Loss of production due to the need for resetting is minimized by setting each machine to sew adequately over a narrow range of fabrics.

5. These trade practices may avoid or induce pucker as explained in the next paragraphs.

B. Sewing procedure

1. It was noted that untreated print cloth showed some puckering when sewed with soft or mercerized thread. This pucker occurred in most of the large number of samples. Analysis of the results of these tests indicated that it was probable that some visible pucker existed in all untreated print cloth items after sewing,

but this pucker would have been moderated or removed by the pressing of the item before final inspection. Therefore it was likely that the item would be acceptable to the consumer.

2. The established conditions and techniques for sewing untreated fabrics appeared to be satisfactory for wash-wear treated fabrics as well. There was no perceptible change in ease of sewing, thread breakage or appearance before pressing. The wash-wear treated items sewed with untreated thread were at least equal and many times better looking (less pucker) than the untreated samples had been.

3. Severe puckering occurred in all untreated samples upon washing. The untreated samples puckered badly and, together with the badly wrinkled background fabric, created a totally unsatisfactory appearance. Pressing was essential. During pressing most of the pucker was reduced or eliminated along with the wrinkles in the background fabric. The pressed samples were satisfactory.

4. The presence of a resin treatment on the fabric and the relatively pucker free appearance of the item before washing led to the expectation that little or no ironing of the wash-wear treated samples would be needed after washing. Actually, after washing there was relatively little wrinkling in the background fabric but the seams puckered badly. This indicated a problem in the relationship of the thread-stitch size and the fabric geometry which might be solved by the use of a thread treated to give it approximately the same characteristics as the fabric with which it was to be used. Tests were then run to determine whether treated threads were the answer.

C. Sewing with treated threads

1. It was already known from discussions with Coats and Clark that earlier wash-wear treatments for cloth had not proved satisfactory for thread. Their research had indicated that the sewability of the thread decreased greatly upon treatment. Since this research did not include some resins now in use, the company agreed to try to produce a treated thread with acceptable sewability. The manufacturers level of resin content was used in treating the threads with two commonly used resins, DMEU and triazine.

2. These threads would have to sew consistently at commercial speeds with the minimum number of thread breaks to be satisfactory. A second factor would be the ability of a given thread to sew a range of fabrics satisfactorily without delicate readjustment of the machine settings and sewing techniques.

3. The treated thread broke frequently even at low speeds. In fact, it was impossible to obtain representative seams for comparison with those sewed with untreated threads.

4. An evaluation of the physical characteristics of the treated thread showed no apparent differences to untreated threads. Physical tests showed that the treated thread was weaker than the same size of untreated thread. But the decrease in strength did not seem to fully explain the almost total loss of sewability. Further examination of the treated thread is planned, particularly in the area of the difference in effect of the two types of resin on the thread. For some reason the triazine seems to have caused less loss of strength. The triazine thread also sewed better.

D. Physics of stitch formation

1. It was found that a piece of untreated or treated print cloth has only minor unevenness before sewing. The yarns were generally lying in the same plane.

There was room enough between the yarns to accommodate the diameter of a sewing thread. The threads being tested were slightly larger than the average diameter of the yarns in the three test fabrics.

2. Knowing the number of stitches to be inserted in a given inch of a fabric, it was possible to calculate the number of additional thread diameters that had to be crammed into the area between interlock points. Since there was a known number of yarns already present in this area, the addition of the thread diameters might cause overcrowding or jamming. When this occurred, the threads and yarns caught in the stitch could not move outside the interlock points but instead rode over or under each other. This would distort the surface of the cloth along the stitch line, causing localized puckering.

3. As indicated in Table 3, it was possible to predict the maximum number of stitches per inch that could be inserted in a known fabric construction without jamming.

4. The finer threads occupied relatively smaller space and it was possible to sew a greater number of stitches per inch without jamming.

E. Effect of stitching direction

1. It was noted that when the line of stitches was sewed straight down the warp direction of a fabric, the stitches were likely to trap the single

warp end along the line of stitches. This was equally true for the single pick of filling yarn on a filling wise seam.

2. Because bias seams run across both yarn systems at an angle at each interlock point the yarns were trapped as in other types of seams, but each stitch trapped a different combination of warp and filling yarns.

3. The stresses set up in the yarn systems by the presence of a line of stitches with its attendant interlock points were equal throughout. But the effect of the stress on a given pair of yarns during bias sewing was rapidly dissipated in all directions as the yarns deformed readily. In the warp of filling seam the stresses fell essentially on a single line of yarns which could not deform as readily. Therefore, not only was deformation restricted to the vicinity of the stitch line, but also the stress was only partially relieved. This concentration of stress led to pucker with both greater frequency and amplitude than stress on the bias could induce.

F. Effect of mercerization on puckering

1. Mercerized thread showed less tendency to pucker than soft finish thread. This was true in all untreated threads.

2. This was explained by reference to earlier work reported on Table II page 9 of Quarterly Report 3. This work showed that mercerized thread was less affected by washing and was less likely to induce pucker due to dimensional changes in the thread itself. It could not be established whether these advantages carried over to treated mercerized threads. The earlier work predicted that these threads would show even less tendency to pucker. The amount of decrease in tendency to pucker was small and may not be discernible. Further work is planned.

G. Effect of washing on the fabrics

1. When the test fabrics were analyzed using Dorkin and Chamberlain's technique, it was found that better results for warp sewing appeared as expected in gingham and broad cloth. For both warp and fill sewing, Permafresh was expected to show the least pucker through the types of fabric.

2. This was explained by the resistance of the yarns in the resin treated fabrics, Permafresh and Belfast, to the tension caused by the contraction of sewing threads after washing. This affected the seam pucker to an undetermined degree. At present time, it is uncertain which factor, the resistance of the yarn to the tension of the thread or the contraction of thread and cloth after washing, is more predominant in causing the change of seam pucker.

H. Effect of stitch length on pucker

1. It was noted that when relatively few stitches per inch were used to sew print cloth there was less puckering in the treated version than the untreated print cloth. As the number of stitches per inch was increased the tendency of both untreated and treated print cloth to pucker also increased. At the highest number of stitches per inch (16 SPI) the untreated print cloth showed less puckering after sewing than the treated print cloth.

2. This change illustrated the effects of the pucker resulting from changes in the dimensional stability of the fabric and thread as well as the effect of yarn jamming.

3. There was some contraction of the thread in all cases but it showed as minor puckering in the treated fabric. The stability of the yarn structure in this fabric permitted it to absorb the relatively low stress that contraction imposed upon it. This stress was induced at relatively few points because fewer interlock points existed per inch.

4. As the number of interlock points increased the ability of the yarn structure to resist deformation was impared. Since the resin treatment caused the yarns to resist deformation the stress was confined to the stitch line. This became additive to the pucker caused by the shrinking of the thread. Severe localized puckering resulted, mostly along the line of stitches. The structure of the untreated print cloth was also stressed but the relatively low stability of its yarns dissipated the stress and reduced localized puckering below that of the treated print cloth.

I. Comparison of visual and photometric rating system.

Previous reports included a description of the photometric device used to record the pucker found in a given seam. During this quarter additional study was made of the nature of the traces recorded by this device and their relationship to the five class rating system provided in AATCC Method 88B.

It was found that many samples could not be classified as belonging in one rating class. Some were better than the lower limit but worse than the upper limit of the rating class. This led to the use of rating intervals between two rating classes. Since it could not be established initially where a particular sample fell in the rating interval, it was impossible to use decimal designations such as 4.3 or 4.1. Instead the interval was designated as 1-2, 3-4, etc., and all samples falling within its limits were so designated.

The curves traced for these samples did show the same pattern of frequency or amplitude.

To express the relationship existing among these samples in mathematical terms it was necessary to measure their pecularities accurately. The following paragraph describes three methods used to accomplish this.

From the analysis of these curves it was determined that the interval between AATCC rating classes is not constant. Further that it becomes increasingly more difficult to differentiate between samples with relatively little pucker. This is explained in part by the random variations existent in the fabric before sewing. These variations may accentuate the pucker induced by sewing or may cause it to blend into the background of the fabric.

The effect of the six key variables on the probability of pucker being induced were treated simultaneously by means of a computer program. This program compared the AATCC visual rating assinged to the samples with the rating assigned to the photometric trace. Comparisons were made of samples before and after washing.

This comparison validated mathematically the experimental work discussed elsewhere in this report. This comparison was based on Method II, the Ratio Method. It was accurate within the limitations of that method. Additional study using the more definitive Method III, the Sine Method, is planned.

J. Mathematical analysis.

This work began with the assumption that the data collected for each fabric and thread were compatible. The problem was to find methods of analysis that would fit the data.

Method I, the area under the curve method, gave one numerical value that would define the magnitude of the tracing but no further information could be gained for this method. It had three major drawbacks: 1) The equation of the curve, f(x), was unknown. 2) Many tracings would give the same numerical value but would not possess identical characteristics. The equation of the curve would be needed to identify each tracing from other tracings with the same value. 3) The method was time consuming.

Method II, the ratio method, was derived from the first method. It shared the same advantages and disadvantages except the third disadvantage of Method I. In work carried on during the last part of the quarter, the ratio method was retained as a check method.

When comparing at the 5% level the odds of any significant differences between two sets of data being due to chance are fewer than 5 out of 100.

Of the relationships studied only 5 relationships of 8 showed a significant difference. They were 2 and 2-3, 2-3 and 3, 3-4 and 4, 4-5 and 5.

Of these five relationships only three showed any significant difference not due to chance at the 1% level. They were 2 and 2-3, 3-4 and 4, 4 and 4-5.

If these data at the 1% level were used, the relationships 2 and 2-3 _and below_ comprised one group, while 3-4 and 4 _and above_ comprised a second group. The relationships 3 and 3-4 fell between the two groups.

This analysis gave three separate groups with characteristics which were described as follows:

Group I (Rating of 2 and 2-3 and below) - intensive localized seam pucker present. Unacceptable.

Group II (Rating of 3 and 3-4 only) - less pucker present. On the border between acceptable and unacceptable.

Group III (Rating of 3-4 and 4 and above) - minimum amount of localized seam pucker present. Pucker tends to blend into the background variations of fabric. Acceptable.

Method III, the sine curve method, had none of the disadvantages of the other two methods. The main advantage of the sine theory was the equation of the curve. The equation provided a means to identify the different curves and made it possible to compare and study the curves.

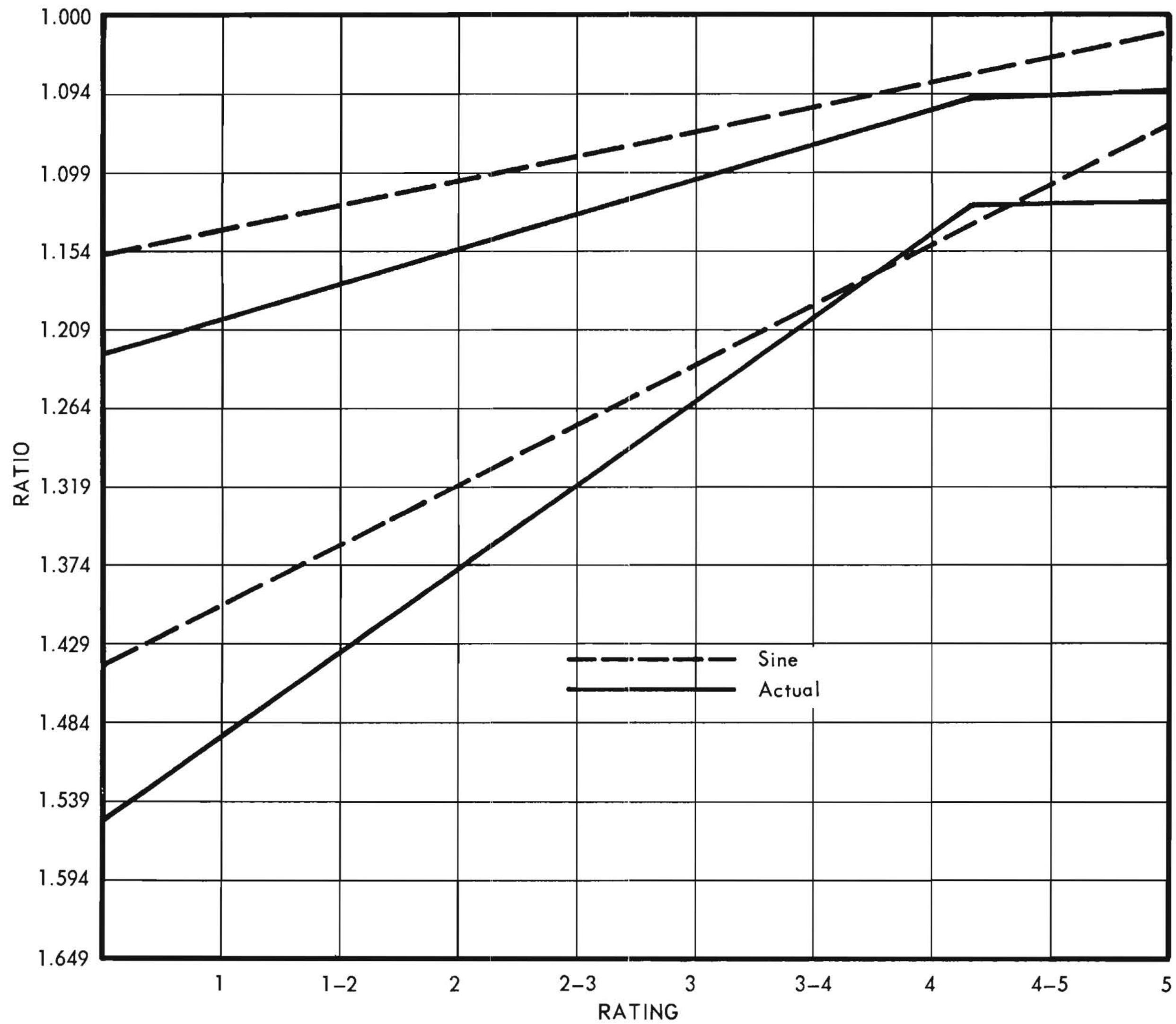
A set of derived curves showed that three groups existed. The first group, class ratings 1 to 3, showed a constant number of puckers with the only change being made in the height of their respective puckers. The only difference between a sample rated class 1 and a sample rated class 3 was in the size of their puckers, not in the number of puckers. The second group, class 3 to class 4, showed a constant height with a change occurring in the number of puckers. The third group, class 4-5 and class 5, showed a constant height and a constant frequency.

The lower classes yielded sine ratios and actual ratios of approximately equal values, but the sine ratios decreased at a faster rate that the actual ratios. It was noted that the actual ratio of class 5 rating increased. In later tests, class 4-5 rating approached 1.000, better than 5 rating. Further work is planned to test this apparent exception.

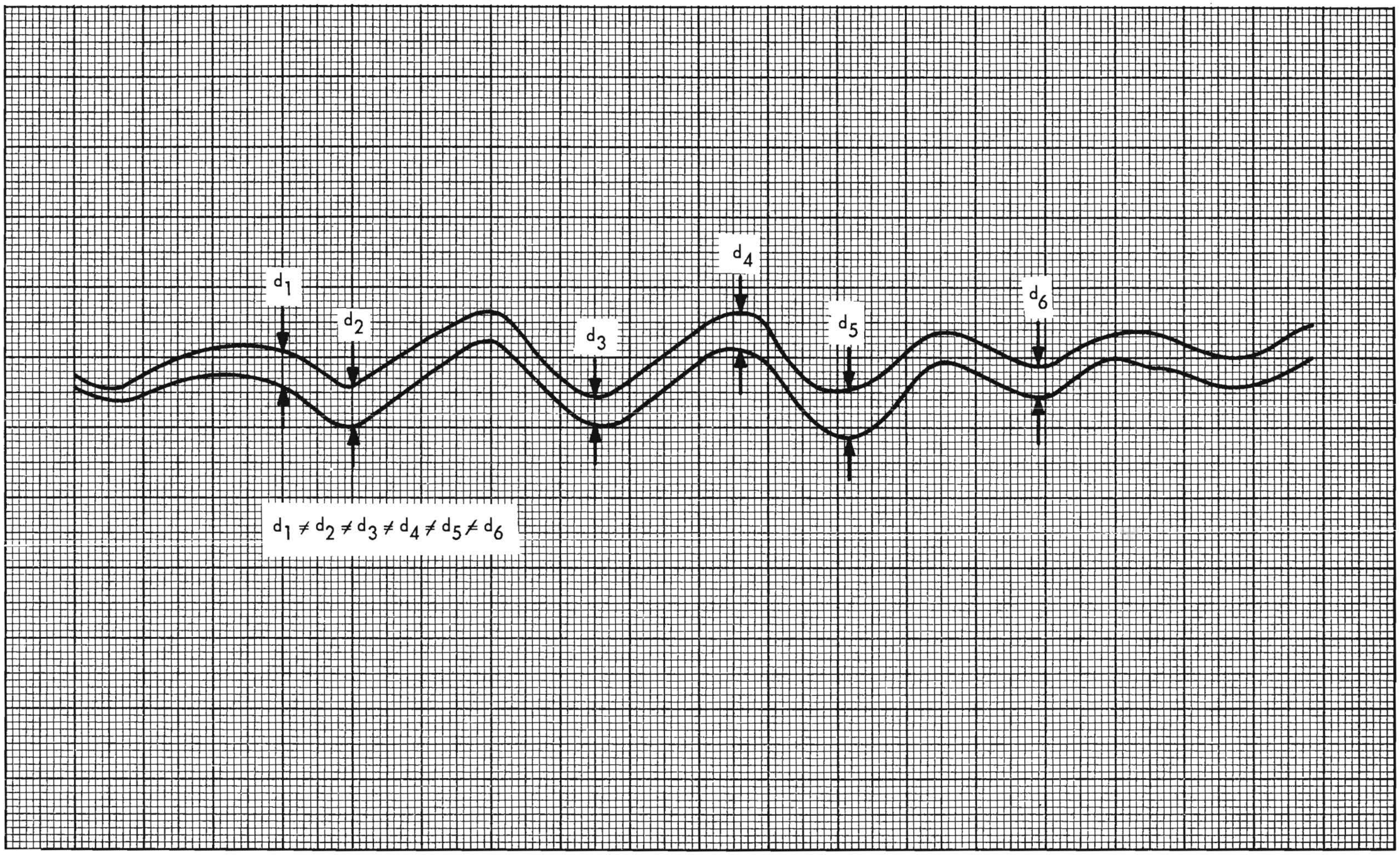
The theory that distortions in the cloth played a large part in causing this difference was tested by comparing the curve of a double ply cloth before sewing with the same piece of cloth with a seam. A significant difference (the region between the two curves) was found. This difference would create a curve with a class 5 rating, although the curve was rated 4-5; this effect was labeled the blending effect. (See Graph 6)

As a further means of comparing the ratios obtained from the sine curves against the ratios of actual curves, a graph was constructed to show the range of the actual curves and the sine ratios in each rating. To find the range of the actual ratios a distribution table was constructed to show the regions of greatest densities through all of the ratings. The region lines were located by human judgment. (See Graph 5)

The sine ratios give straight line limits and the actual ratios give limits that bend in the class 4 rating and level off in the class 4-5 and class 5 ratings. This may be due to the blending effect discussed earlier.



Graph 5. Regions of Greatest Densities.



Graph 6. Blending Effect.

IV. CONCLUSIONS

Work completed this quarter confirmed systematically earlier empirical studies. It was determined that the tendency of a given combination of facric and thread to induce pucker can be predicted. In turn, at least part of this pucker was minimized by choosing a thread whose characteristics paralleled those of the fabric. Although this step did reduce pucker resulting from yarn jamming, a second type caused by the inherent stability of the wash-wear treated fabrics remained a problem. Use of the minimum number of stitches per inch commensurate with the design of the item minimized this puckering.

No appreciable advantage in ease of sewing was detected while using mercerized instead of soft finish thread. The mercerized thread did enhance the appearance of the samples.

Detailed mathematical treatment of the data indicated that the AATCC rating system was inconsistent. Instead of five discrete classes, nine classes composed of five discrete classes and four indiscrete classes were used to rate all samples. The five classes given by the AATCC Technical Manual bore no direct mathematical relationship to each other. The other four had even less relationship due to being intervals rather than definite ratings.

Methods I and II can not be used as complete analysis because they give only the magnitude of a tracing and nothing else about the tracing. They can be utilized as means of checking or indicating the nature of the size of the tracing, though.

Method III will fulfill all requirements for a complete analysis. In initial tests it has divided the samples into three main groups. Further testing is needed, though, to complete all of the analysis procedure.

Some study has been made into when a "pucker" is and is not a pucker but an inherent distortion in the cloth found before sewing. This made it hard to distinguish any difference between samples rated class 4-5 and class 5. Further work is needed along this line.

Further work is needed before it can be determined whether treated threads reduce the tendency of a seam to pucker. Steps have been taken to determine the availability of other types of threads mentioned in the contract.

It appears likely that the sewing conditions and techniques used for untreated threads are not suitable for use with treated threads.

There was marked decrease in sewability of the test threads after wash-wear treatment. One factor, the decrease in strength, has been noted; other factors will have to be determined and studied.

A review of the progress to date indicated that further work along the same lines of research is warranted.

QUARTERLY REPORT 6

PROJECT A-786

PHYSICS OF SEAM PUCKER

JAMES L. TAYLOR and FRANK J. CLARKE

Contract 12-14-100-719(72)

15 SEPTEMBER 1965 to 14 DECEMBER 1965

Prepared for
U. S. Department of Agriculture
Southern Utilization Research and Development Division
New Orleans, Louisiana

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

GEORGIA INSTITUTE OF TECHNOLOGY
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15 SEPTEMBER 1965 to 14 DECEMBER 1965

Prepared for
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SOUTHERN UTILIZATION RESEARCH AND DEVELOPMENT DIVISION
NEW ORLEANS, LOUISIANA

ABSTRACT

The study of seam pucker which is a result of distortion in the fabric induced by the penetration of the needle into the fabric was continued this quarter. High speed photography was used to record actual sewing and stitching without thread. These films were analyzed and the distortion characterized in terms of its amount and shape in each sewing direction on the test fabrics.

Needle penetration created distinctive waves of distortion in each fabric. The pattern or shape of the distortion varied from a sharp cornered square when print cloth was sewed to a bell shaped rounded corner pattern in oxford cloth.

The direction of sewing also influenced the distortion. Sewing in the warp and filling direction caused waves that crossed the line of stitches. As they did so, they were trapped and sewed in place where they appeared as puckers. The waves in bias sewing did not cross the line of stitches so they could not be trapped; therefore, puckering did not occur.

Attempts to apply the classical cases of wave theory to the patterns that were observed were unsuccessful. Further work is planned.

Work on the predetermination of sewability of a thread through a study of its physical characteristics was continued. Breaking strength, elongation, abrasion resistance and work of rupture were related for all test threads. An apparent correlation was found between abrasion resistance and work of rupture as an index of sewability. Further work to relate the dynamic fatigue of threads to this predetermination of sewability was begun.

A new all-cotton mercerized sewing thread treated with resin but left uncured during sewing was evaluated. The results of the predetermination tests indicated that the thread would sew satisfactorily but would be unstable upon laundering. Both laboratory tests and an evaluation in a commercial sewing plant were conducted this quarter. The results were as predicted. The manufacturer has revised the recommended procedure for curing this thread. Further work is planned.

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I. INTRODUCTION

A. General

The format of this report differs from previous reports in that each aspect of the work done during this quarter has been presented fully before another aspect was introduced. In this way the rationale behind this experimental work, the work itself, the discussion and the conclusions arrived at were brought together for more convenient reading and study. The recommendations and plans for future work arising from this work have been consolidated to show their relationship to the whole research on the basic physics of seam pucker.

B. Work performed

The major contribution this quarter was further study of actual sewing to aid in the determination of the nature of the wave patterns that occur in the fabric during sewing. Three distinctive patterns were observed and recorded by high speed photography. These patterns were studied using the classic cases of wave theory but none were fully applicable. The wave formation appeared to be related in severity to the direction of sewing. As had been determined empirically the tendency to pucker was greatest when sewing in the warp direction and least when sewing the bias direction.

Much of the work done on thread this quarter concerned post cured resin treated all-cotton threads intended for use with post cured fabrics. Evaluations of these threads in relation to seam pucker were made on campus and at a quality sewing plant.

Earlier attempts to predetermine the tendency to pucker through yarn jamming were continued using the post cured resin treated all-cotton thread with the original test fabrics. Measurements of thread diameter and the dimensional stability of the fabric and thread were used as indices in this study.

A study of the contribution of breaking strength and elongation to the sewability of a thread indicated that work of rupture was a better criterion for predicting sewability.

C. Conferences

Mr. Donald R. Meyers, Union Special Machine Company, conferred with the research team on September 15, 1965. He described two basic causes of seam distortion which are the result of machine action itself. First, there is distortion caused by the feeding action of the machine during sewing. Second, there is distortion resulting from the locking of the stitch into the fabric three stitches after the stitch is formed. Union Special is working to minimize both types of distortion. Four major auxiliary methods of feeding the fabric through the sewing mechanism have been either developed or improved by the company. These methods seek to reduce the amount of force exerted on the fabric as it is being sewed and reduce the amount of over-feeding behind the needle. Overfeeding is caused by the position of the presser foot on the presser bar. When the front of the presser foot is up, the fabric is gathered as it is sewed; when the back of the presser foot is up, the fabric is stretched. This factor becomes very important in sewing since it is believed that after a stitch is formed, it is not set or locked into place until approximately three stitches later. The distortions caused by feeding are then locked into place and emerge as puckering, either as a puckered seam before washing or as a seam that is stretched and which, upon washing, recovers and appears puckered.

All sewing on this project has been done with Union Special needles size 183GL-036. This style is the one commonly used in commercial sewing of fabrics and threads of the type used in this research. Mr. Meyer suggested the use of a thin, sharp pointed needle, Union Special size 183GRS-036. These needles have been obtained but not yet evaluated as a means of reducing pucker.

During a conference on September 28, 1965, Mr. Howard R. Seitz, Chemist, Technical Development Department, Dixie Yarns, Inc. offered several suggestions on sewing techniques when using his company's post cured resin treated all-cotton thread. He agreed to submit samples of new versions of the company's threads for evaluation.

Mr. Porter Brown, Chief, Quality Control Department, Arrow Shirt Company, Atlanta, stated on December 1, 1965 that preliminary evaluation of Dixie Yarns post cured resin treated threads had not shown any advantages over standard untreated cotton threads. His staff plans to conduct further evaluation.

Mr. Frank Comstock, Product Development Department, Deering Milliken Research Corporation discussed the problem of needle damage during his visit on October 10, 1965. He stated that a study made at their laboratories showed that needle damage to a yarn system was practically insignificant. Mr. Comstock suggested improvements in the photoelectric seam scanning device that would make it more useful in industry as a quality control device. He recommended a conference on the entire project be held at their Spartanburg headquarters.

Based on Mr. Comstock's recommendation, Mr. Clarke conferred with Dr. Michael Lock, Chief, Product Development Department, Mr. Donald Gardiner and Mr. Frank Comstock at Deering Milliken Research Corporation on November 16, 1965. After a review of the work done on campus, Mr. Clarke was told that Deering Milliken recommended the use of a thermoplastic synthetic fiber thread for sewing the blended synthetic fiber and cotton fabrics now being manufactured. Although this thread does not create less pucker in sewing, it softens when the sewed article is pressed and extends as necessary to relieve the stress upon it, leaving an unpuckered seam. No suggestions were offered on the use of cotton thread in sewing these or all-cotton durable press fabrics.

On November 8, 1965 Mr. Clarke conferred with Mr. S.E Murdoch, Manager, Mooresville Division, Burlington Industries concerning their all-cotton durable press fabrics. Samples of these fabrics are being obtained for preliminary study before preparing proposals for further research on the problem of puckering in durable press fabrics.

Dr. H. W. Guenther, Chief, Chemical Section, Coats and Clark Research Laboratories examined the work being done during his visit on November 11, 1965. He recommended several changes in sewing technique for the special test threads prepared by his laboratory. He offered to prepare other test threads containing semi-durable swelling agents as required in the contract.

Mr. H. K. Gardner stated by telephone that his laboratory would prepare additional test threads. Two cones of Wolf quality Coats and Clark soft finish thread were sent to the laboratory for treatment.

Mr. R. Morris, Canton Cotton Mills, earlier offered the use of their laboratory in evaluating work already done on double needle sewing. This company is a major producer of denims. Through it this work is in turn co-ordinated with the H. D. Lee Company plant at Jasper, Georgia. A summary of work on these heavier weight fabrics will be included in the next report.

D. Literature search

Mr. H. K. Gardner of Southern Regional Research Laboratories drew to the attention of the team a thesis entitled The Effects of Selected Variables on the Amount of Seam Pucker Exhibited in Three Wash-and-Wear Fabrics, by Mrs. Adele Smith of Auburn University. Mrs. Smith's work related to domestic sewing but contained no new information for this project.

An article on dynamic fatigue in the Journal of Applied Physics, June 1949, entitled "Dynamic Measurements of Polymer Physical Properties" by J.W. Ballou and J.C. Smith, DuPont, Buffalo, New York was reviewed. The article discussed three techniques for measuring the elastic and dissipative properties of high polymers in fiber and film form. An instrument utilizing these techniques has been constructed.

II. RESEARCH PERFORMED

A. Study of stitch formation

Work done during the Summer Quarter, 1965, included a mathematical analysis of the tracings obtained from photometric tracings of test seams sewed under various conditions. This analysis showed that the curves were variations in a single family of sine curves generated by the harmonic motion in stitch formation. When actual sewing at production speed was observed, the harmonic motion appeared to produce waves in the cloth which were locked into place by the seam. The relationship of these waves and their frequency and amplitude appeared to vary with the direction of sewing, but in all cases there was a recurring pattern attributable to the harmonic motion of stitch formation.

This quarter research was conducted to study the action of specific parts of the sewing machine as well as sewing with and without thread. A stroboscope (Strobotac Type 1531-A made by General Radio Corporation) was used to slow the motion of the machine. It was set to flash at 4,850 cycles per minute which matched the motion of the sewing machine at full speed.

Initially, observations were made of the action of the thread guides, thread takeup and upper tension regulator areas during sewing. The stroboscope was positioned 12 inches from the head of the machine so that it was fully illuminated. This was followed by a study of needle action to observe the actual penetration of the fabric by the unthreaded needle held in one position on the fabric. The needle was then threaded with Ticket 70/2 untreated soft thread and untreated broad cloth was sewed at full speed with the presser foot down. After observations had been made, the presser foot was raised about 1/4 inch so that the fabric remained in the same position on the throat plate for the remainder of the observations.

From these observations it was determined that the fabric resisted penetration of the needle on the downstroke and was deflected down into the hole in the throat plate before penetration occurred. On the upstroke the fabric clung to the needle and rose with it to a point about 3/16 inch above the throat plate. At this point the needle withdrew and the fabric fell back on the throat plate. Various patterns of waves appeared during this cycle with the needle as the point of generation.

Initially, it had been expected that a circular pattern of distortion would be observed because the penetration occurred perpendicular to the plane of the cloth. This pattern should have resembled the circular pattern observed when a stone hits a pool of water.

When sewing broad cloth, print cloth and oxford cloth in the warp direction, three different wave patterns were observed.

Figure 1 shows the trapezoidal pattern observed in broad cloth. The longer diagonal ran in the warp direction. This fabric construction is 141 warp x 63 filling yarns per inch.

Figure 2 shows the square pattern observed in print cloth. There were equal lines of force running parallel to both yarn systems. This fabric construction is more nearly balanced at 85 warp x 77 filling yarns per inch.

Figure 3 shows the bell shaped pattern observed in oxford cloth. This pattern did not contain the sharp corners and changes of direction displayed by the broad cloth and print cloth patterns. This fabric contains 94 warp x 48 filling yarns per inch.

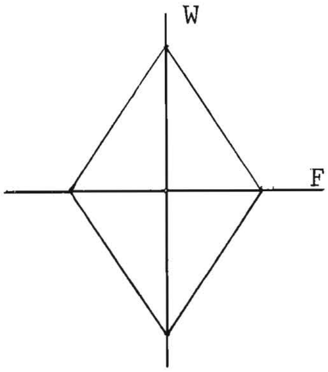

Figure 1. Broad Cloth

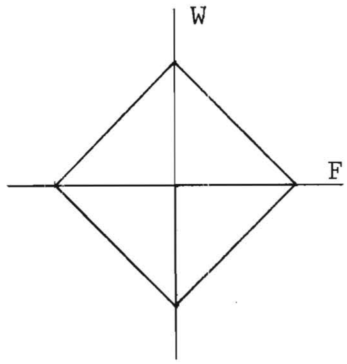

Figure 2. Print Cloth

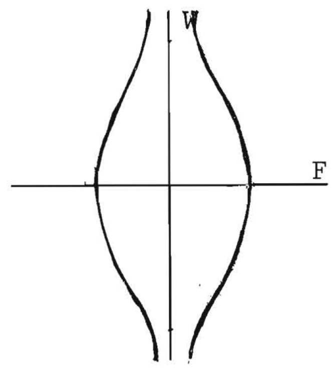

Figure 3. Oxford Cloth

Even at slow motion it was impossible to calculate the velocity, period and amplitude of these wave patterns. An attempt to use a still camera with a Polaroid back (4 x 5 Super Speed Graphic using Type 57 Polaroid film) was successful in that motion was stopped and momentary distortions were recorded. These pictures contained only static data and were only of limited value in calculating the characteristics of the observed waves.

A high speed motion picture camera (Fastax 16 mm. camera, 100 feet in 1.75 seconds) was used to make three sets of films. The first set showed flagging and wave patterns in a single ply of fabric. The second set showed sewing without thread on a single ply of fabric. The third set showed sewing with thread. Each film was marked at 1/60 second intervals.

The film showing flagging and wave patterns was made of a Permafresh print cloth specimen on which a 25 cm. square grid had been drawn. This grid was subdivided into 1 cm. squares with sides parallel to the warp and filling yarns. The specimen was positioned under the presser foot so that the sewing direction would be parallel to the warp direction. The unthreaded needle was positioned at one intersection of the two yarn systems which coincide with an intersection of two grid lines. All penetrations occurred at this one point during the filming with the presser foot raised 1/4 inch and the machine operated at full speed.

The second film was made with the same specimen turned 90° so that sewing would be parallel to the filling direction.

The third film was made of another specimen on which the same grid had been drawn but on the bias with a 45° orientation to the warp and filling yarn systems.

The three films made with the presser foot lifted showed that one large wave was generated each time the needle moved up or down with several smaller waves preceding and following it.

One specimen used contained a crease which ran diagonally between the operator and the point of needle entry. During sewing as a wave struck this crease, part of the wave rebounded towards the needle. The crease appeared to act as a carrier of the wave energy, transmitting the energy in both directions along its axis. The crease also generated identical waves on the opposite side of the crease from the needle.

The effect of the presser foot as a dampening agent had already been noted so a fourth film was made of sewing without thread but with the presser foot down. The two ply specimen used contained a series of marks 1 cm. apart which ran parallel to the warp direction and down the center of the specimen.

The waves generated in sewing were much smaller than those generated with the presser foot raised. They were smaller in size and further apart when sewing began than they were at the end of the seam. The largest waves occurred near the end of the seam. This would seem to indicate a cumulative effect either in distortion or in delayed additive energy that resulted in larger waves.

When the needle was threaded and a fifth film made, it was observed that the wave pattern was approximately the same as that obtained when sewing with the presser foot down and an unthreaded needle. A new wave characteristic was noted in this film. The waves alternated from in front of to behind the needle. When they were present at one point, they were absent at the other and vice versa. A pattern of wave crests occurred as sewing progressed, each one in the same relative position each time regardless of the number of stitches that had been sewed.

An analysis of these high speed films was made using a Bell and Howell Model 173 Time and Motion Study Projector. It was found that conventional methods could not be used to calculate the velocity of the waves which resulted from the distortion during sewing. The dampening effect of the presser foot created conditions that require additional study. Dr. Wilton King, School of Engineering Mechanics, Georgia Tech has agreed to examine this problem further to determine whether a separate proposal for research in this area is warranted.

The analysis showed that when sewing in the bias direction the wave of distortion moved parallel to the bias direction. Energy traveled along both yarn systems but a resultant wave was also generated. The direction of the resultant wave was the vector sum of the warp and filling energies, but since the waves did not cross the line of stitching, pucker was not produced as a wave formation. Puckering might be present from other causes but not from wave formation. This partially explained the relatively low puckering observed in bias versus warp or filling sewing.

The alternate appearance and disappearance of the wave pattern may be explained by comparing the fabric to a vibrating string where certain loops and nodes appear at regular intervals. Since the end of the fabric was free to vibrate, it would not act as a node but would allow the body of the fabric to continue to act with some frequency but the amplitude would change.

It was observed that the presser foot was most effective as a propagating device in the bias direction.

On the other hand, sewing in either warp or filling direction produced energy which again traveled along both yarn systems, but also crossed the line of stitching. Therefore, the distortion was sewed into position as a pucker. A general rule derived from this analysis was that the least puckering occurred when the stitch line paralleled the path of greatest resistance. That is the bias direction. As sewing moved from the bias to the filling direction, puckering would increase. Then in the warp direction maximum puckering would occur because sewing would be along the path of least resistance.

Approaching this concept from the wave viewpoint, it was observed that warp yarns are necessarily tighter than filling yarns in these test fabrics. The yarns have a greater density which would permit higher velocities in the energy passing along them. Filling yarns would accommodate lower velocities. So sewing in either warp or filling direction would trap sufficient energy in either system to create pucker.

One explanation of the reduction of puckering in resin treated fabrics would be that their stiffness has been increased and with it their resistance to distortion.

B. Dynamic fatigue in thread

One problem in determining the cause of failure or reduced sewability of a given thread is a method of simulating the dynamic stress encountered in sewing. Work done at DuPont on the sonic modulus of monofilaments contained a possibility that a vibrating mechanism could be constructed to simulate the loading of the thread.

Work has begun using a 15 inch radio speaker (Olson Model 5503) to yield vibrations at approximately 5,000 cycles per minute when driven by a 83 cycles per second oscillator. A thread connected to the center of the cone of this speaker will be vibrated in about the same manner as a sewing thread is during sewing. No further data are available at this time, but work will continue during the next quarter.

C. Evaluation of post cured threads

Dixie Yarns, Inc. has recently offered the commercial sewing industry a wholly cotton mercerized sewing thread that has been resin treated but not cured. The amount, type and method of application of the resin are patented. Two cones of yarn were furnished for use in this investigation. One cone of Style 031-67-2 represented the treated version being marketed. The second cone contained Style 031-67-3, the untreated version (not for commercial sale).

These threads were evaluated in the same manner as those originally prepared for this project. Evaluation began with the adjustment of the sewing machine to standard sewing conditions used for all other threads. The Dixie Yarns untreated thread was then placed on the machine.

Four warp direction sewing samples each of untreated, Belfast and Permafresh broad cloth were prepared using 12 stitches per inch and maximum speed to sew two flat seams parallel to each other and two inches apart. No modification of standard sewing conditions was required.

Six warp direction sewing samples for each of the same test fabrics were then prepared using the treated version of this thread. It was necessary to adjust the upper tension regulator one quarter turn to increase the tension before the optimum stitch was obtained. No other changes were necessary.

The samples were evaluated by three observers using the overhead evaluation procedure in AATCC Method 88B. Photometric tracings were made of a three inch segment of one seam on each sample.

Two samples of each fabric sewed with untreated thread were laundered and two were held as unlaundered controls.

Two samples of each fabric sewed with treated thread were held as controls, two were cured but not laundered and two were cured and laundered together with the two untreated samples.

Curing the samples followed the procedure agreed to by Dixie Yarns as follows:

1. Press samples with dry hand iron set at cotton setting. Open and press flat each seam. This simulated the "seam busting" operation used in some commercial sewing.

2. Hang vertically in a 325^{o} F. oven (163^{o} C.) and allow to remain for three minutes.

3. Remove and condition for 24 hours at 70^{o} F. and 65% relative humidity.

4. Evaluate visually and make photometric tracings.

5. Launder in accordance with Washing Procedure II and Drying Procedure A of AATCC Method 88A. Repeat cycle five times.

6. Evaluate visually and make photometric tracings.

Table I shows the results of this evaluation. No evaluation of these threads to sew post cured fabrics was made. Subsequent to this evaluation Dixie Yarns revised the recommended curing procedure to 335^{o} F. for 15 minutes. This procedure has not been evaluated.

The results obtained when sewing the test fabrics with untreated thread indicated a possible problem. Although the sewability of the untreated version of the thread was satisfactory, the resulting specimens were poor in appearance with ratings of 1 through 3. This was explained by the relatively low dimensional stability of the untreated thread. The thread appeared to be sewing satisfactorily but shortly after the specimen was removed from the machine, severe puckering was observed, apparently the result of contraction after tension had been removed from the thread. There appeared to be only minor variations in quality of the seams sewed on untreated or treated fabrics.

This apparently low stability worked in favor of the sewer when the treated version was used. Although the sewed specimens were poor in appearance, pressing followed by curing greatly improved their appearance. This improvement was completely lost during laundering which seemed to indicate that it had been caused by pressing.

Pressing gave only temporary improvement and it was lost when the resin failed to stabilize the fabric upon curing.

Work on this project has been confined to precured and untreated fabrics; however, the increasing use of post cured fabrics has necessitated a reconsideration of the scope of the work being done. After consultation with Mr. Gardner of SRRL, it was decided to confine the study to the present test fabrics but also to seek other treated fabrics for possible investigation under another contract.

The Dixie Yarn post cured thread represented the first apparently successful attempt to induce crosslinking in the thread without greatly reducing its sewability. This was proved during the study when the treated version sewed both untreated and precured fabrics satisfactorily.

Earlier work using post cured threads determined that none of them would sew satisfactorily. These threads contained the manufacturer's level of unreacted resin plus lubricants. The Dixie Yarns thread contained a much smaller quantity of unreacted resin and a lubricant. It was not apparent whether the difference in lubricants improved sewability or the decrease in resin content. Since the resin was unreacted in all cases, it should not have affected the strength.

A separate evaluation by Cluett Peabody at its Atlanta plant utilized post cured fabric and post cured Dixie Yarns thread. The desired improvement in puckering was not obtained. Further field evaluation at Cluett Peabody (shirtings) and Canton Cotton Mills (denims) is planned before a proposal for future research is submitted.

TABLE I

SEWING UNTREATED, BELFAST AND PERMAFRESH BROAD CLOTH
WITH DELAY CURED THREAD (DIXIE YARNS STYLE 031-67-2 AND 031-67-3)

Fabric and thread type	Rating before cured	Rating after pressed and cured	Rating after washed
Untreated broad cloth			
Mercerized untreated	3	-	2
Delay cured	4	5	1-2
Belfast broad cloth			
Mercerized untreated	2	-	<1
Delay cured	1	4	<1
Permafresh broad cloth			
Mercerized untreated	2-3	-	<1
Delay cured	1-2	4	<1

< indicates a rating less than the standard rating.
- indicates that samples were not pressed and cured before laundering.

D. Physical analysis of Dixie Yarns threads styles 031-67-2 and 031-37-3

1. Calculation of the optimum stitch length

As reported on Page 12 of Quarterly Report 5 it is usually desirable to use the largest number of stitches per inch in many exposed seams where appearance is a factor. But if the available space in a stitch is fully occupied by the yarns trapped between the interlock points, there will be insufficient space for the thread being used to sew. This jamming of the yarns causes them to move out of a common plane resulting in puckering.

Table II contains the data on sewing Dixie Yarns threads into the test fabrics and yet avoiding yarn jamming. For example, the length of one stitch when sewing 10 stitches per inch is 2.540 mm. Comparison of this space with that needed for the threads and yarns in one stitch shows that all test fabrics can be sewed with 10 stitches per inch without jamming. But when 14 stitches per inch are sewed, the space available in one stitch decreases to 1.814 mm. The space needed for untreated print cloth for example is 1.935 mm. Therefore, yarn jamming and puckering will occur. Other combinations were analyzed in a similar way and the maximum number of stitches per inch that could be sewed without jamming were calculated.

2. Determination of actual thread size

A toolmaker's microscope with microcaliper was used to measure the diameter of each thread (see Quarterly Report, Page 11). The results were as follows:

Thread Type	Diameter in mm.
Style 031-67-3 (untreated)	0.270
Style 031-67-2 (treated-uncured)	0.243

TABLE II

OPTIMUM STITCHES PER INCH USING DIXIE YARNS THREADS
STYLE 031-67-2 AND 031-67-3

	Number of SPI	10	12	14	16	Max. no. of SPI
	Theoretical Length of stitch (mm)	2.540	2.117	1.814	1.588	
Space occupied by yarns and thread per stitch	Untreated print cloth (warpwise)					
	Untreated	2.385	2.122*	1.935*	1.794*	11.9
	Delay cured Treated	2.304	2.041	1.854*	1.713*	13.2
	Belfast print cloth (warpwise)					
	Untreated	2.234	1.997	1.827*	1.700*	13.8
	Delay cured Treated	2.153	1.916	1.746	1.619*	15.3
	Permafresh print cloth (warpwise)					
	Untreated	2.312	2.062	1.883*	1.749*	12.8
	Delay cured Treated	2.231	1.981	1.802	1.668*	14.2

* Jamming of yarns will cause movement out of common plane.

It was found that mercerized thread had decreased in diameter after treatment and before curing. This was attributed to elongation of the thread during treatment under tension. Evaluation of the dimensional stability of this thread is discussed in a later section of this report. The decrease in diameter between treated and untreated versions parallels results obtained on other test threads. This change in diameter has a marked effect upon the ability of the treated resin to sew more stitches per inch. Table II indicates an average increase of 1.5 stitches per inch over the untreated version of the same thread size. This factor alone should increase the interest in this approach to fabric and thread compatability provided that the stability of the treated thread remained at a satisfactory level.

3. Measurement of thread stability

As discussed in paragraph 2, if the stability of these threads was high it would enable their use in sewing a larger number of stitches per inch because of their relatively smaller thread diameter. But the stability had to be high if puckering due to changes in dimension upon laundering was to be avoided. Otherwise the puckering induced by dimensional instability would be intensified by puckering induced by yarn jamming as the effective length of the stitch decreased. This stability was evaluated through the use of the technique of Dorkin and Chamberlain. Results obtained on other test threads and details of the technique were reported in Quarterly Report 3.

The results obtained with Dixie Yarns threads were:

Thread Type	Untreated	Delay Cured Treated
Extension (A) %	0.77	0.59
Contraction (B) %	1.96	2.93
A + B %	2.73	3.52

For comparison of dimensional stability, a portion of the delay cured thread was cured by the procedure recommended by Dixie Yarns. A hank of thread (approximately 150 yards) was hung in a drying oven without tension. The oven temperature was increased to 325° F. in 2 minutes and held at that temperature for 2 minutes. The hank of thread was then removed from the oven and conditioned at 70° F. and 65% relative humidity for 24 hours before testing.

A portion of the cured thread was then boiled and measured using the technique of Dorkin and Chamberlain mentioned above. Results were as follows:

Contraction after curing, before washing (%) = 1.00

Contraction after curing and washing (%) = 2.45

It was determined that the sum of the extension under load (A) plus the contraction in boiling water (B) of these threads was higher than that of mercerized threads tested earlier (see Quarterly Report 3). This indicated the increased likelihood of puckering. The treated and cured version showed lower stability than the untreated version. This was also found upon examination of the sewed and laundered samples. These results indicated the likelihood of poor sewing performance all around. The field evaluation made by Cluett Peabody showed good sewability but poor performance upon laundering.

E. Predetermination of sewability by examination of certain physical characteristics of a thread

A major factor affecting sewability is the ability of the thread to withstand sudden starts, rapid movement and abrupt stops without loss of dimensional stability. This is usually described by breaking strength determinations.

A second factor to be considered is the elongation of the thread under load and its recovery after the load has been removed. This can be measured satisfactorily.

A third factor is less commonly used because it is the measure of the work of rupture or breaking load per unit area of a specimen.

A fourth factor is resistance to abrasion, first from the components of the machine, then the needle, then thread-to-yarn and thread-to-thread in the fabric.

If these four factors could be related they should predict the relative sewability of a given thread without actual sewing. Work done this quarter developed some of these relationships and showed the feasibility of predetermination.

Breaking strength and elongation tests had been made during the previous quarter on 16 cones of Coats and Clark test threads Ticket nos. 70/2 and 80/2. These tests were made by Coats and Clark Laboratory, Atlanta, as part of their physical evaluation procedure. Results of these tests are recorded in Quarterly Report 5, Table 2, pages 9 and 10.

The breaking strength and elongation tests were made this quarter using an Instron Tensile Tester Model TT-C with an integrator to record the work of rupture. Coats and Clark threads Ticket nos. 70/2 and 80/2 and Dixie Yarns threads styles 031-67-2 and 031-67-3 were used. The average breaking strengths, elongation percentages and work of rupture are recorded in Table III.

A study was made to determine the extent of correlation between the breaking strength and abrasion resistance of the selected test threads. Table IV shows a comparison of the data obtained from the breaking strength tests and abrasion resistance tests. Percentage increase or decrease in the breaking strength was calculated from the breaking strength for the soft untreated version. The percentages for the treated mercerized threads were calculated from the breaking strength of the mercerized untreated version. Percentages were calculated in a like manner for the changes in abrasion resistance.

Table V shows a comparison of the work of rupture and abrasion resistance. Percentage changes in this table were calculated in the manner described above.

The abrasion resistance of the selected test threads was measured using a No. 2 Walker Abrader made by Coats and Clark, Inc. This instrument was designed to measure thread-to-thread abrasion by looping the test specimen around an oscillating post situated between two fixed screws that hold the thread in contact with the oscillating post at minimum tension. This tension was not measurable. The oscillating post moved in a path 1/2 inch long. The abrasion resistance of the thread was measured by the number of oscillation cycles required to break the thread under minimum tension.

Results of this test are recorded in Table IV. The percentage decrease in breaking strength and abrasion resistance of each treated thread as compared to its respective untreated version is shown after each value.

In analyzing the results obtained it was found that using a single value to describe the relationship between breaking strength and abrasion resistance resulted in a theoretical four zone array into which all threads would fall. Three zones would be made up of threads with poor sewability as follows:

a) Low abrasion resistance-high breaking strength

b) High abrasion resistance-low breaking strength

c) Low abrasion resistance-low breaking strength

TABLE III

AVERAGE BREAKING STRENGTH, ELONGATION AND WORK OF RUPTURE OF COATS AND CLARK THREADS TICKET NOS. 70/2 AND 80/2 AND DIXIE YARNS THREADS STYLES 031-67-2 AND 031-67-3*

Ticket nos.	Thread finish	Treatment	Cured/ uncured	Breaking strength (lbs.)	Elongation (%)	Work of rupture (lbs. in.)
Coats and Clark threads						
70/2	soft	untreated	uncured	1.48	7.2	40.6
00/2	merc.	untreated	uncured	1.96	5.2	40.6
80/2	soft	untreated	uncured	1.46	7.6	46.2
80/2	merc.	untreated	uncured	1.58	5.4	32.8
70/2	soft	DMEU	uncured	1.27	6.2	31.8
70/2	soft	DMEU	cured	1.26	6.0	29.0
00/2	merc.	DMEU	cured	1.66	4.5	30.8
80/2	soft	DMEU	uncured	1.26	6.8	35.0
80/2	soft	DMEU	cured	1.04	5.9	25.4
80/2	merc.	DMEU	cured	1.36	4.8	24.8
70/2	soft	triazine	uncured	1.24	5.9	26.4
70/2	soft	triazine	cured	1.42	6.3	36.8
00/2	merc.	triazine	cured	1.76	5.0	34.6
80/2	soft	triazine	uncured	1.19	6.9	32.6
80/2	soft	triazine	cured	1.30	7.3	39.6
80/2	merc.	triazine	cured	1.55	5.3	32.4
Dixie Yarns threads						
031-67-3	merc.	untreated	uncured	1.60	4.8	41.0
031-67-2	merc.	delay cured	uncured	1.90	3.3	29.0
031-67-2	merc.	delay cured	cured	1.71	4.5	28.4

* Instron settings: load C-5, jaw speed- 10 in./min., chart speed-10 in./min.

TABLE IV

A COMPARISON OF BREAKING STRENGTH AND ABRASION CYCLES OF UNTREATED AND RESIN TREATED THREADS

	Ticket No. 70/2				Ticket No. 80/2			
	Breaking strength		Abrasion		Breaking strength		Abrasion	
Thread type	lbs.	% change*	Cycles	% change*	lbs.	% change*	Cycles	% change*
Soft untreated	1.48	-	10.5	-	1.46	-	11.8	-
Merc. untreated	1.96	+32.5	7.8	-25.7	1.58	+8.1	7.3	-38.1
Soft DMEU-uncured	1.27	-14.2	3.3	-68.5	1.26	-13.6	2.2	-81.3
Soft DMEU-cured	1.26	-14.8	3.3	-68.5	1.04	-28.6	2.2	-81.3
Merc. DMEU-cured	1.66	-15.3	4.5	-42.3	1.36	-13.9	3.5	-52.0
Soft triazine-uncured	1.24	-16.1	4.5	-57.1	1.19	-18.5	1.8	-84.7
Soft triazine-cured	1.42	-4.0	9.7	-7.5	1.30	-11.0	7.3	-38.1
Merc. triazine-cured	1.76	-10.2	8.8	+12.8	1.55	-1.8	8.3	+13.6
031-67-3 merc. untreated**	1.60	-	18.2	-	-	-	-	-
031-67-2 merc. treated-uncured**	1.90	+18.6	13.0	-28.6	-	-	-	-
031-67-2 merc. treated-cured**	1.71	+6.8	7.2	-60.4	-	-	-	-

* % change indicates an increase (+) or decrease (-) in breaking strength and abrasion resistance.
** identifies Dixie Yarns threads, untreated (031-67-3) and delay cured treated (031-67-2).
- indicates no measurement made.

TABLE V

A COMPARISON OF WORK OF RUPTURE AND ABRASION CYCLES OF UNTREATED AND RESIN TREATED THREADS

	Ticket No. 70/2				Ticket No. 80/2			
	Work of rupture		Abrasion		Work of rupture		Abrasion	
Thread type	lbs.in.	% change*	cycles	% change*	lbs.in.	% change*	cycles	% change*
Soft untreated	40.6	-	10.5	-	46.2	-	11.8	-
Merc. untreated	40.6	0.0	7.8	-25.7	32.8	-29.0	7.3	-38.1
Soft DMEU-uncured	31.8	-21.6	3.3	-68.5	35.0	-24.2	2.2	-81.3
Soft DMEU-cured	29.0	-28.5	3.3	-68.5	25.4	-45.0	2.2	-81.3
Merc. DMEU-cured	30.8	-24.0	4.5	-42.3	24.8	-24.4	3.5	-52.0
Soft triazine-uncured	26.4	-34.9	4.5	-57.1	32.6	-29.3	1.8	-84.7
Soft triazine-cured	36.8	-9.3	9.7	-7.5	39.6	-14.2	7.3	-38.1
Merc. triazine-cured	34.6	-14.6	8.8	+12.8	32.4	-1.3	8.3	+13.6
031-67-3 merc. untreated**	41.0	-	18.2	-	-	-	-	-
031-67-2 merc. treated-uncured**	29.0	-29.2	13.0	-28.6	-	-	-	-
031-67-2 merc. treated-cured**	28.4	-30.7	7.2	-60.4	-	-	-	-

* % change indicates an increase (+) or decrease (-) in work of rupture and abrasion cycles.
** identifies Dixie Yarns thread, untreated (031-67-3) and delay cured treated (031-67-2).
- indicates no measurement made.

All threads with high resistance to abrasion and high breaking strength were expected to display good sewability. This could not be established. Some threads with low abrasion resistance and fair breaking strength would sew. Conversely, some threads with high abrasion resistance and high breaking strength sewed badly. It appeared that breaking strength was not a good index of sewability when related to abrasion resistance. Work of rupture was selected as an alternative. When used in this way, it would measure the dynamic ability of a thread to withstand the sudden starts and stops that are typical of power sewing. More definitive results were obtained when relating abrasion resistance and work of rupture.

Earlier work reported in pages 6 and 7 of Quarterly Report 5 was substantiated by this study. Threads that would sew did have high work of rupture and high abrasion resistance.

Soft cured triazine treated thread showed the best results of the original group of test threads. The plot of the work of rupture and abrasion resistance for this thread fell on the borderline of good sewability. Actually, it would sew but only at reduced speed.

The Dixie Yarns thread exhibited unusually high abrasion resistance but fair work of rupture. This thread sewed well. The presence of thread lubricants probably contributed to these results, but all test threads contained some lubricant. Furthur study is needed on this point,

One reason advanced for the correlation of work of rupture and abrasion resistance was that measurements of breaking strength assume that the entire section of the simplest spring-dashpot model is involved in sewing. Actually only the spring portion reacts. Therefore, measurement of the work of rupture where the force was largely absorbed by the spring while the dashpot failed to react was a closer approximation of actual sewing conditions.

III. CONCLUSIONS AND FUTURE PLANS

A. No appreciable advantage resulted from sewing precured fabric with post cured threads. No further work is planned.

B. Inconclusive results were obtained on the use of post cured threads to sew post cured fabrics. Work will continue including that with outside collaborators.

C. Study of the engineering mechanics involved in sewing appears fruitful. Further work is planned, possibly to the extent of another separate proposal.

D. Determination of sewability and compatability of thread and fabric without actual sewing shows promise. Work will continue.

E. Study of dynamic fatigue as a cause of thread failure will begin this quarter and continue indefinitely.

F. The photometric instrument for determining the intensity of seam pucker is still under development. Work will continue.

G. Blended fabrics and all-cotton durable press fabrics will be evaluated to the extent that a decision can be made on a proposal to work on them.

H. Evaluation of other types of test threads will continue.

QUARTERLY REPORT 7

PROJECT A-786

PHYSICS OF SEAM PUCKER

JAMES L. TAYLOR and FRANK J. CLARKE

Contract 12-14-100-719(72)

15 DECEMBER 1965 to 14 MARCH 1966

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GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

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QUARTERLY REPORT 7

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SOUTHERN UTILIZATION RESEARCH AND DEVELOPMENT DIVISION
NEW ORLEANS, LOUISIANA

ABSTRACT

By means of a sonic fatigue device which subjected the test threads to ome of the stresses which occur in actual sewing, it was determined that the ighest probability of thread failure existed at the stitch interlock point. hese results agreed with earlier reports obtained by sewing with these xperimental threads.

High speed motion pictures were used to isolate the contribution of arious factors to the deformation of the fabric that occurred in sewing. t was found that the major factor was the feed dog-presser foot combination. he needle penetration appeared to be a minor cause of deformation.

Further work on the interrelation of abrasion resistance and work of upture as determinants of sewability led to a five zone array into which all est threads fell as sewable, not sewable or indeterminant.

Unfortunately, neither the SRRL slack mercerized, resin treated and estretched nor the Dixie Yarns resin treated threads evaluated this quarter ave satisfactory sewability. Work to improve both types is continuing. Other hreads containing semi-durable swelling agents or film forming agents are eing prepared for analysis next quarter.

Full details on this research will be reported during the Sixth Annual otton Utilization Conference in April.

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I. INTRODUCTION

. General

Work during this quarter consisted of a continuation of the study of he deformation that occurs in fabric during sewing. New work included an valuation of slack mercerized and restretched threads which had been esin treated. These threads did not possess satisfactory sewability. nother group which has been slack mercerized but not fully restrethced efore resin treatment is being prepared at SRRL for further study here.

An additional approach to determining the factors involved in thread reakage was demonstrated by means of a sonic fatigue device which used ibrations to simulate the dynamics of actual sewing conditions. Excellent orrelation was obtained.

This technique will be a part of the analysis to be used next quarter n special threads now being prepared by Coats and Clark Research Laboratory. ncluded will be some threads with film forming agents and others with semi-urable swelling agents. These are two different approaches to providing reater effective length in a stitch without decreasing the seam efficiency.

The practicability of predetermining thread sewability through the nterrelation of abrasion resistance and work of rupture was demonstrated nd a plot made of the threads prepared this quarter. These threads fell nto five zones according to their relative sewability.

3. Conferences

A major conference on this project was arranged by Mr. Gardner at SRRL this quarter. Dr. Taylor, Mr. Clarke, and Mr. Belser briefed the laboratory staff on the work already done and planned. Three examples of wave deformation were described by means of high speed motion pictures after which it was agreed that further pictures were warranted.

The SRRL staff asked that a paper on this work be presented at the Sixth Annual Cotton Utilization Conference in April.

A conference was held at Canton Textile Mills laboratory on January 5, 1966, during which the problems of puckering in double needle sewing were discussed. Experimental sewing was also done at this laboratory for evaluation later.

Mr. Willard Ferguson conferred with the staff of the Product Development Section, Deering Milliken Research Corporation on February 14, 1966, concerning this work and recent developments in all-cotton durable press fabrics.

. Publicity Releases

This work received three major publicity mentions during this quarter. First, a one-half hour radio broadcast over WGST was devoted to describing and discussing this research. Later, the Atlanta Journal, Atlanta North Side News, and the Daily News Record, picked up and printed extensive releases on the project. Similar coverage was obtained throughout Georgia. Favorable comments were also received from Arrow Shirt Company, a contributor to this research. Although an offer was made for the research team to appear on the local ABC-T.V. station, it was declined in view of the excellent exposure obtained earlier.

This research was also discussed at the Fashion Careers Seminar on January 22nd, at the Monroe Rotary Club on January 10th, and a church group on January 9th.

II. RESEARCH PERFORMED

. Dynamic behavior of sewing threads

Considerable work was done during previous quarters to predict the bility of thread to sew at high speeds, but no system was devised to accur- tely describe sewability. Conventional test methods used, i.e., breaking trength, elongation and abrasion resistance, are measurements of the static erformance of thread. As such, they do not always accurately describe ewability which is dynamic. Sewing includes a complex of vibrations in the hread set up by the thread take, needle and feed action.

Work done by J. W. Ballou and J. C. Smith at DuPont on the sonic modulus f monofilaments was described in an article entitled "Dynamic Measurements f Polymer Physical Properties", in the Journal of Applied Physics, 1949, olume 20. It contained the possibility that a vibrating mechanism could be esigned to simulate the dynamic action involved in high speed sewing.

This simulation would induce fatigue in the specimens under sinusoidal xtension during varying time, when the following relations exist:

Distance is expressed as $e = \hat{e} \sin \omega t$

where e = amount of extension at time t

$\hat{e}$ = amplitude of the strain

ω = frequency or angular velocity in radians per second

herefore, the velocity of the extension will be:

$$\frac{de}{dt} = \hat{e}\omega \cos \omega t$$

his is sinusoidal, not linear.

For this work, $\hat{e} = 1/8$ inch

$$\omega = 83 \text{ cycles times } 2\pi \text{ radians/second}$$

$$e = 1/8 \sin (83)(2\pi)t \text{ inches}$$

ınd the velocity

$$\frac{de}{dt} = (\frac{1}{8})\ (83)(2\pi)\ \cos\ (83)(2\pi)t \text{ inches/second}$$

ıimplified as

$$\frac{de}{dt} = \frac{83}{4}\ \pi \cos 166\pi t$$

'herefore, the stress at time t is:

$$f = \hat{f} \sin (\omega t + \delta)$$

where $\hat{f}$ = amplitude of the stress,

$$\delta = \tan^{-1} \frac{\varkappa\omega}{E}$$

$\varkappa$ = viscosity coefficient of the fiber

E = Young's modulus in dynes/cm^2

A sonic fatigue device (Figure 1) was designed to simulate the relation-hips existing between the thread, the tension regulator or last thread guide, nd the interlock point between the plies of a stitched fabric. The device rovided 1/8 inch traverse forward and 1/8 inch traverse backward on each ycle to simulate the alternate feed and take-up of the stitch cycle. A thread eing sewed at 5000 RPM would be moved through this distance in a typical titch cycle.

The source of vibrations was used to simulate the vibrations induced by he feed and take-up of the machine. It consisted of a 15 inch radio speaker Olson Model S-503) driven by a 83 cycles per second oscillator (Hewlett Packard odel 200B). The vibrations were amplified and fed to the modified speaker cone o yield about 5000 vibrations per minute with a traverse of $\pm$ 1/8 inch from rest.

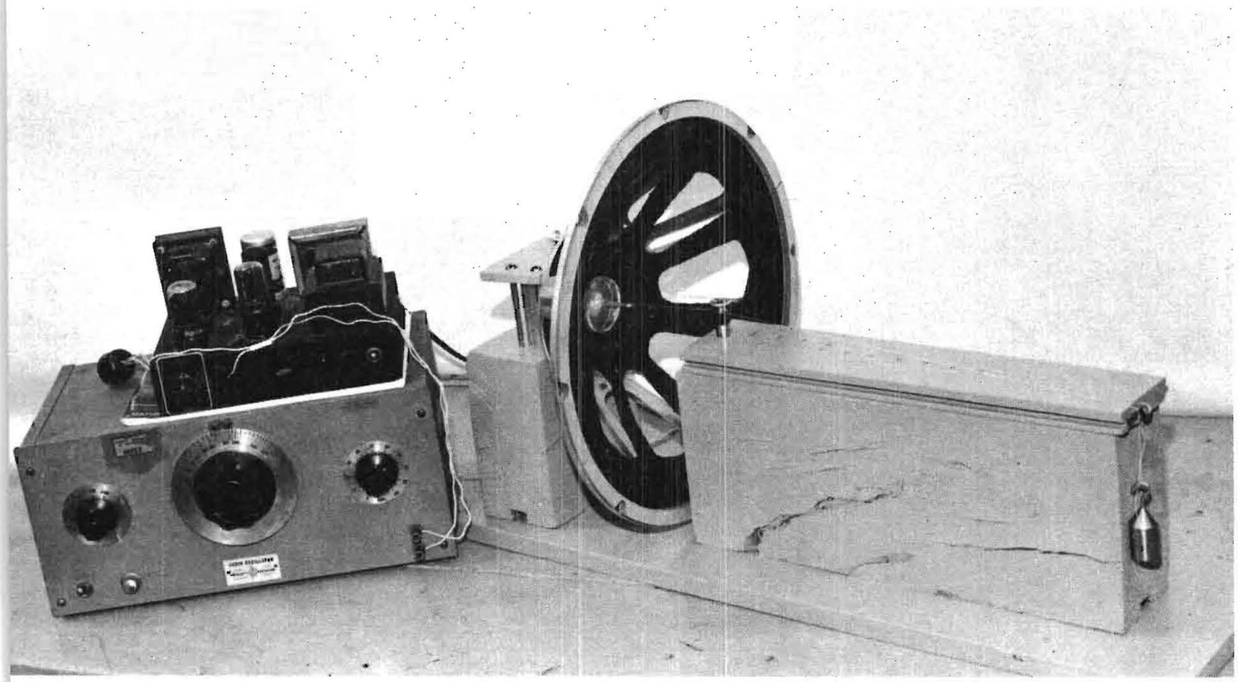

Figure 1. Sonic fatigue device

A plastic hook was cemented to the speaker cone so that any movement nduced in the cone would be induced in it as well. (Plastic was selected ecause of its low mass which would interfere with transmission less than etal or wood.) One end of each specimen was tied to this hook so that the otion of the hook was passed to the specimen.

A stationary jaw was selected to simulate the last tension on the sewing achine. This machine tension alternately opens and closes between stitch cycles ut is closed during any one cycle.

To determine the optimum distance (gauge) between the fixed jaw and the vibrating hook, a series of observations was made of the wave pattern generated by the device with a thread in position between the hook and the fixed jaw.

It was found that this test differed from static tests in which the stress and strain were either continuously increasing or continuously decreasing. This test involved oscillating stresses and strains. Since the inertia of the specimens was a factor, the stress and strain along the length of the sample varied at any given time. When a stress in the front of a vibration was transmitted along the tensioned thread, time was required for its effect to become apparent and for the resultant transient oscillation to die away.

Therefore, a short gauge was preferable to allow rapid dissipation of the transient oscillations. A 4-inch span was chosen because it also closely approximated the distance between the last thread tension and the interlock point between plies of the fabric under the presser foot. This test ignored the abrading effects of the needle and interlock and the flexing effect of the thread in the eye of the needle. It was designed to determine where failure was most likely to occur along the span.

Sixteen threads consisting of two ticket sizes and eight treatment variations were tested. Each specimen was tied to the oscillating hook by a loop knot and pulled tight. The thread was then run through the fixed jaw and attached to a 100 gram weight. After a few seconds to allow the weight to come to rest, the fixed jaw was clamped on the thread so that the effective span between oscillating hook and fixed jaw was 4 inches.

The vibrator was started and run to first observed fatigue. Fatigue was defined as the initial parting of any fiber or group of fibers in the specimen.

When failure did not occur before 20 seconds the device was stopped to ·emove the induced elongation in the span. The fixed jaw was opened and the ;hread allowed to run out through it under the 100 gram load until there was ·xactly 4 inches of thread between the hook and the fixed jaw. The jaw was :losed and vibrating resumed until failure occurred. The time to break, ex- luding the initial 20 seconds, was noted for each sample. Twenty-five samples ›f each thread were tested and the average fatigue point in seconds computed 'or each thread. The results are shown in TABLE I.

TABLE I

A COMPARISON OF SONIC FATIGUE
AND ELONGATION FOR COATS AND CLARK TEST THREADS

hread	Ticket No. 70/2 av. time to break (in seconds)	Elong.	Ticket No. 80/2 av. time to break (in seconds)	Elong.
oft, untreated	109.2	7.2	87.7	7.6
oft, DMEU,uncured	14.8	6.2	5.4	6.8
oft, DMEU,cured	4.7	6.0	13.8	5.9
oft, triazine,uncured	13.6	5.9	11.5	6.9
oft, trianzine,cured	18.9	6.3	42.1	7.3
erc., untreated	6.2	5.2	2.4	5.4
erc., DMEU, cured	2.1	4.5	0.5	4.8
erc., triazine,cured	6.3	5.0	1.7	5.3

An analysis of these data shows that the mercerized threads broke in a significantly shorter time than did the soft versions. A partial explanation for this is that upon mercerizing, fibrilar orientation takes place and cellulose crystallinity decreases significantly. The degree of crystallinity depends on the amount of tension applied during the mercerization process. Decreased crystallinity made the mercerized thread less elastic and more susceptible to fatigue than the soft thread.

The resin treatments used on twelve of the sixteen threads tested are thought to have decreased their elasticity below that of the untreated version of the same thread. In fact, some of these threads broke during the initial 20 seconds of vibration. Performance was poorest on the mercerized MEU cured thread.

A high correlation exists between these data on the actual elongation previously determined for each thread. TABLE I shows the two sets of results.

It appears that the sonic fatigue time of a thread is directly related to its elasticity. An examination of the nature of the breaks that occurred in the threads shows that a shearing or tearing of the fibers had occurred rather than a single complete rupture of the entire cross section of the thread. The breaking of a single strand of the yarns comprising the thread altered the tone being emitted by the speaker so it was possible to accurately measure the time and nature of the initial failure and subsequent rupture.

One purpose of this test was to determine where the breaks occurred. If the thread was of equal strength along the entire span, the likelihood of rupture would be evenly distributed. But the thread was clamped at one end where flexing and bending was induced. It was tied at the other end where interthread friction would occur at the knot as well as flexing and bending.

Analysis of the breaks showed that 50% of the breakage occurred at the cone, 10% occurred at the clamp, and 40% occurred at random along the remaining length of the span.

The higher incidence of breaks at the cone agrees with the higher incidence of breaks at the interlock point which had been found during experimental sewing. It appears that these breaks are caused by the stress induced in the thread as the knot (or stitch) is pulled tight.

In turn, the strain on the thread is transmitted towards the tension where it arrives later and with its force partially dissipated. Therefore, it is likely that fewer breaks will occur at the tension.

The probability of breaks between the tension and interlock point appears related to the random irregularities or weak place in the threads. It seems more likely that the strain will be passed on over the weak places rather than cause a failure unless the weak place is, coincidentally, a knot or flex point.

This work specifically ignored part of the flexing and the effect of abrasion on the thread, for instance, as it passes through the eye of the needle. A much more complicated instrument which would permit the thread to travel forward through the eye of a needle while being vibrated, will be needed to complete the simulation of the sewing machine stitch formation. Design and construction of this device is considered to be beyond the scope of this research.

. Study of stitch formation using high speed motion picture technique

During the previous quarter, a series of high speed motion pictures was made which revealed characteristic wave motion patterns for warp, filling, and sewing (see Quarterly Report 6, pages 6-11). A detailed study of these motion pictures showed a positive relationship between the direction and frequency of wave propagation and the intensity of puckering. SRRL personnel encouraged further study in this area through the use of the high speed motion picture technique. They suggested that both machine and cloth variables be considered because it appeared that this approach would prove profitable in identifying the effect of certain variables on seam pucker.

Sixteen film strips were made with a high speed motion picture camera (Fastex, 16 mm.) to identify the effect of the following variables on seam pucker:

1. the feed dog
2. the presser foot
3. single ply vs. double ply sample
4. needle penetration
5. thread penetration
6. the direction of sewing
7. varied positions of the feed dog

A combination of these variables was selected for each film and alternated so that each variable could be isolated and studied separately. Samples of Permafresh print cloth (16" x 22") were used. Each sample contained a series of marks 1 cm. apart which ran parallel to the warp direction and down the center of the sample for filling sewing and at a 45° angle to the warp for bias sewing. Warp sewing was not included as a variable because earlier work showed that fillings and bias sewing were more comparable.

The initial film was made by sewing without the needle and the presser foot up. The only contact between the sample and the sewing mechanism was at the feed dog teeth. This test was to determine the effect of distortion caused by the feed dog action alone (variable 1). A single ply sample was used because earlier work showed that single ply gave greater distortion than double or multiple plies.

When the machine was operated at full speed, only a slight vertical movement of the sample above the feed dog was noted. This movement was not sufficient to produce noticable waves beyond the feed dog.

However, when a sample was sewed with the needle removed and the presser foot down (variable 2), a wave-like pattern was observed. It appeared that when the sample was held in position by the presser foot and the feed dog, the vertical movement of the feed dog transmitted energy to the sample. This energy in the sample traveled along the yarn systems producing wave-like motions along the lines of least resistance, the bias. The lateral movement of the sample by the feed dog caused waves to be propagated along the probable line of stitching, both in front of and behind the presser foot. It was concluded that waves of deformation occur whenever there is positive contact between the presser foot and the feed dog.

When a double ply sample (variable 3) was sewed with the needle absent and the presser foot down, the wave pattern described above was observed again, except that the intensity of the waves was lessened. This decrease in intensity resulted from an increase in the rigidity of the sample.

With the interaction of the presser foot and feed dog on single and double ply samples established as components which cause deformation during sewing, a fourth variable, needle penetration, was studied. Earlier work showed hat sewing with the needle in place and the presser foot up caused intense aves in the sample called flagging. Now, when a single ply sample was sewed ith the needle in place and the presser foot down, the same characteristic ave pattern described above was observed. The intensity of the waves was the ame as when sewing without a needle. Neither the wave pattern nor the intensity f the waves was effected by needle penetration. When a double ply sample was ewed, the wave pattern was the same, but the intensity was lessened to the same extent as when a double ply sample was sewed without the needle present. It appeared that the sample was held taut by the presser foot resting on the feed dog teeth causing the sample to have drum-like properties. When the needle penetrated the sample, any deformation caused by the needle was reflected by the boundaries established by the contact between the presser foot and the feed dog. Therefore, it was concluded that deformation caused by needle penetration was not additive to the deformation caused by the positive contact between the presser foot and the feed dog.

When a sample was sewed with the needle threaded (variable 5) with mercerized, untreated thread, Ticket No. 70/2, and with the presser foot down, the characteristic wave pattern was observed again with no change in the intensity of the waves. It was concluded that any deformation caused by the thread was not additive but was masked by the distortion which resulted from the contact between the presser foot and the feed dog.

Samples showing the above five variables were all sewed in the filling direction. To determine the effect of a change in the direction of sewing (variable 6), a single ply sample was sewed in the bias direction with the needle in place and with the presser foot down. A wave pattern was observed that differed from the characteristic wave pattern described above for sewing in the filling direction. Waves did not cross the probable line of stitching but were propagated parallel to the probable line of stitching. The sample did not move freely as it was being sewed but encountered drag from contact with the table. This drag appeared to account for the change in wave propogation, i.e., the hinge effect. Tension on the fabric would be required during sewing to eliminate this drag.

On a double ply sample sewed in the bias direction, wave propagation was the same, but the intensity of the waves was lessened apparently due to the increased rigidity of the sample.

The final sequence was made of sewing with the needle present, the presser foot down and the position of the feed dog varied. The normal position of the feed dog, with the back of the feed dog (the edge away from the operator) slightly higher than the front had been optimized for the sewing of the test fabrics. A film was made of sewing with the feed dog in this position as a starting point or control around which to vary the position of the feed dog. In the first variation from the optimum, the feed dog was tilted so that the front was flush with the throat plate and the back was at the original height. The film of this variation showed essentially the same wave pattern as the control except that the waves crossing the probable line of stitching were very sharp, and there was a slight reduction in the amplitude of the waves.

As a second variation, the feed dog was tilted until the back was flush with the throat plate and the front was at the original height. The wave pattern was the same, with sharp waves crossing the probable line of stitching and a slight reduction in intensity.

As a third variation, the feed dog was repositioned at its original height and tilt, then lowered to one-half the distance to the throat plate. The film of sewing with this feed dog position, with the needle present and the presser foot down, showed the same wave pattern as the control except that the ntensity of the waves was reduced more than for the two variations described bove.

The feed dog was not dropped completely out of contact with the sample ecause logic indicated that the feed dog was essential to movement during sewng. Without the feed dog present, the presser foot merely pressed down in lace. It did not rock or oscillate to produce waves in the sample. However, uring actual sewing in which the feed dog is in contact with the sample and he presser foot down, some movement of the presser foot can be observed. This ovement of the presser foot may be somewhat additive to wave propagation.

C. Predetermination of sewability - abrasion resistance vs. work of rupture

During the previous quarter several methods of predetermining the sewability of threads were examined (see Quarterly Report 6, page 20-26). The method found to most accurately describe sewability properties when compared with actual sewability was a comparison of abrasion resistance vs. work of rupture. These data for selected experimental threads were recorded in TABLE V, Quarterly Report 6, page 25. Threads with high abrasion resistance and high breaking strength had good sewability. Threads with high abrasion resistance and low work of rupture had poor sewability. Threads with low abrasion resistance and high work of rupture had poor sewability also; but, threads with both low abrasion resistance and low work of rupture were virtually unsewable.

All threads fell into this theoretical four zone array. But it was difficult to tell by the Table into which of the four zones certain threads fell. Further work showed that a graph was the best method for recording these data in a way that would be easy to recognize as sewable and unsewable threads.

A graph (Figure 2) was set up so that units on the x-axis represented work of rupture and units on the y-axis represented abrasion resistance. Units on the x-axis were set equal to units on the y-axis. With the graph composed of equal units on both axes, a line drawn at a 45° angle would indicate that any change in the work of rupture would show an equal change in the abrasion resistance.

Data for the abrasion resistance and work of rupture for Coats and Clark soft and mercerized threads, treated with DMEU and triazine resins, uncured and cured and Dixie Yarns delay cured treated threads were obtained from TABLE V, Quarterly Report 6. These data for the new lot of Dixie Yarns special treated threads (Style Nos. 033-36-1 through 033-36-5) and for the SRRL slack mercerized, restretched threads were obtained from breaking strength and elongation tests and

Key to Figure 2. Predetermination of sewability-abrasion resistance vs. work of rupture.

Thread No.	Finish	Treatment
Coats & Clark		
1	soft	untreated
2	merc.	untreated
3	soft	DMEU, uncured
4	soft	DMEU, cured
5	merc.	DMEU, cured
6	soft	triazine, uncured
7	soft	triazine, cured
8	merc.	triazine, cured
Dixie Yarns		
9	merc.	untreated (031-67-3)
10	merc.	delay cured, uncured (031-67-2)
11	merc.	delay cured, cured (031-67-2)
12	merc.	moderate level resin, uncured (033-36-1)
13	merc.	moderate level resin, plus polypropylene softner (033-36-2)
14	merc.	minimum level resin (033-36-3)
15	merc.	moderate level resin plus a special lubricant (033-36-4)
16	merc.	untreated-control (033-36-5)
Coats & Clark		
17	soft	untreated
18	slack merc.	restretched untreated
19	slack merc.	restretched DMEU, cured

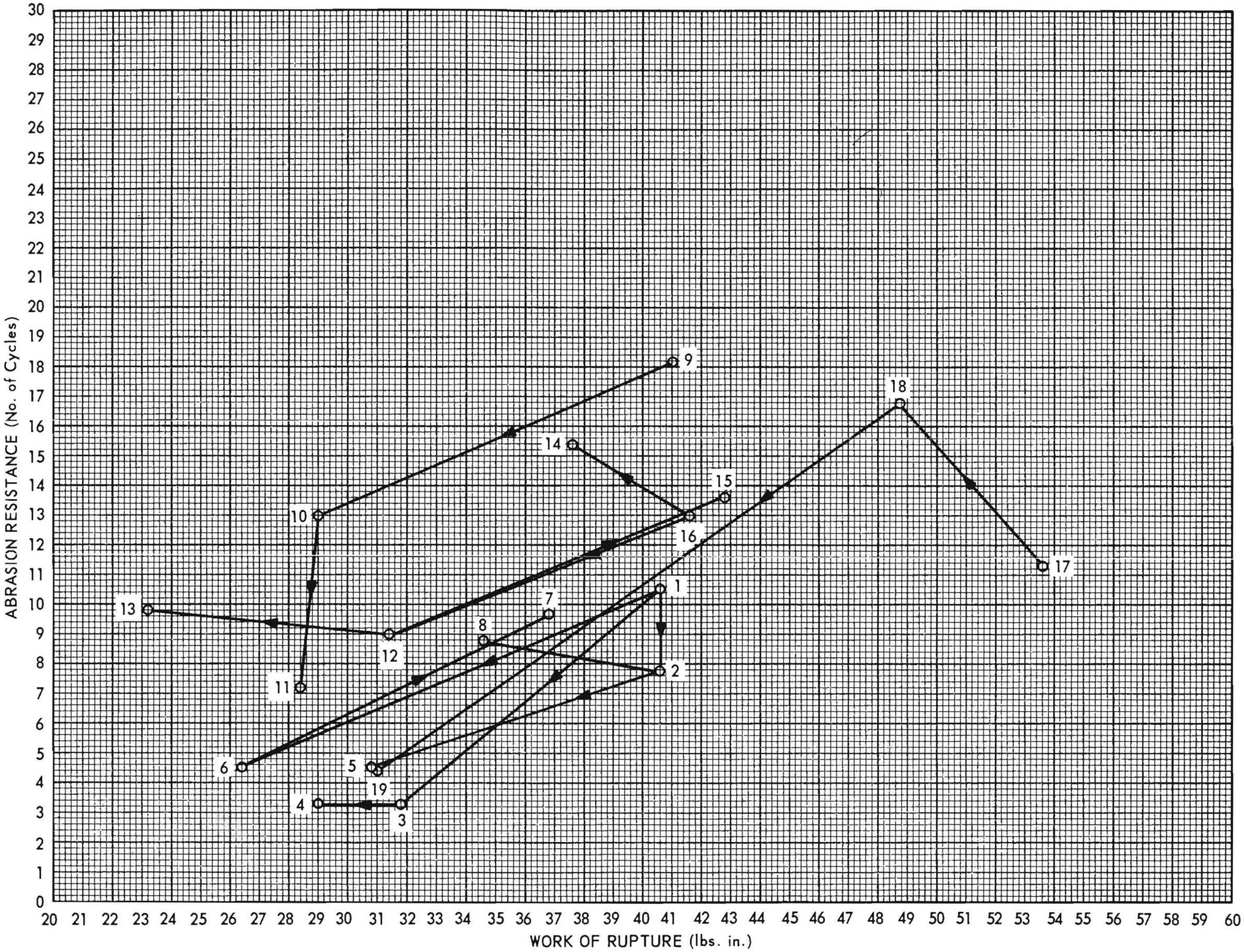

Figure 2. Prediction of Performance - Treated vs Untreated Threads.

abrasion resistance tests made during the present quarter. All threads were Ticket No. 70/2. (See Quarterly Report 6, pages 21 and 22 for procedure).

The corresponding points for abrasion resistance and work of rupture for each thread were plotted on the graph. These points also fell into a theoretical four zone array on the graph when compared with actual sewability. Figure 3 shows these four zones; the boundaries of which are not clearly defined.

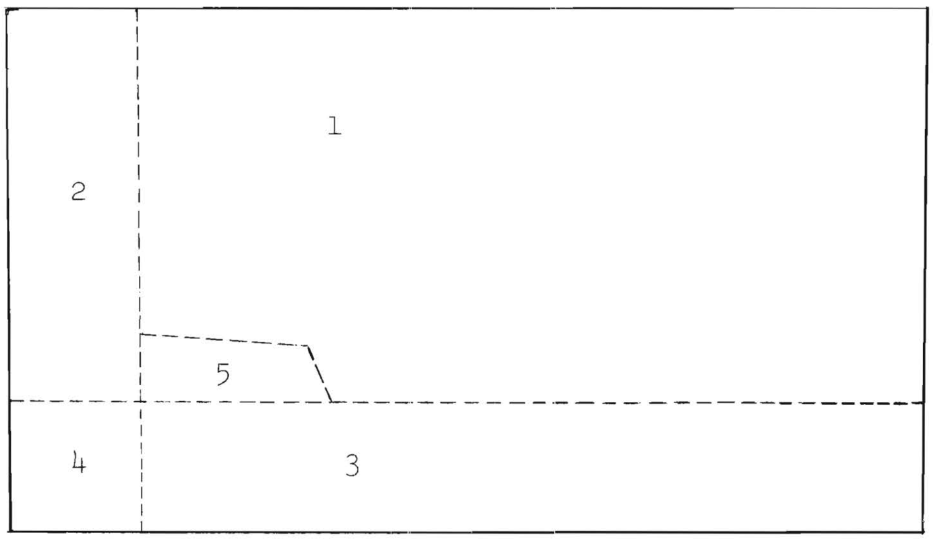

Figure 3. Zones of theoretical sewability

Zone 1. High abrasion resistance (above 7 cycles) - high work of rupture (above 28 lb. ins.) (good sewability). All threads except those listed below.

Zone 2. High abrasion resistance - low work of rupture (poor sewability). Dixie Yarns mercerized, moderate level resin treated thread with a polypropylene softner.

Zone 3. Low abrasion resistance - high work of rupture (poor sewability). Coats and Clark soft, DMEU, uncured thread; soft, DMEU cured thread; and mercerized, DMEU, cured thread.

Zone 4. Low abrasion resistance - low work of rupture (poor sewability). Coats and Clark soft, triazine, uncured thread.

Results of actual sewability tests when compared with the four zone array on the graph, showed that several threads which, although plotted in the sewable zone, had poor sewability. The soft and mercerized triazine treated threads (cured), the moderate level resin treated thread, and the delay cured thread (cured) fell in this catagory. These threads should sew, but their performance was not good enough to rate them as good sewing threads. From this work it seemed evident that a fifth zone was required. The boundaries of this zone were less clearly defined than those of the original four zones. Threads fill- ing within Zone 5 have marginal sewability that may vary among lots, cases or even cones to the extent that they would not be suitable for commercial high speed sewing. These threads may vary greatly in work of rupture but only slightly in abrasion resistance.

D. Analysis of variations among thread treatments

Work done in predicting sewability established a basis for studying the effects of various treatments on thread. A method was developed for expressing in simple mathematical terms the relationship of the points in the graph (Figure 2). This made it easier to analyze the effects of the various treatments on thread.

Lines were constructed on the graph to connect the points plotted for related threads with and without various treatments. These lines represented changes in abrasion resistance and work of rupture due to different treatments such as mercerization, resin treatment, curing, etc. Arrows on these lines indicate the direction of change, whether an increase or decrease, as a result of treatment.

The slope of each line was calculated using the formula $\tan \theta = y/x = m$, when y = abrasion resistance and x = work of rupture. Values of m were expressed in fractions rather than whole numbers to indicate whether abrasion resistance or work of rupture was increased or decreased, and positive and negative signs were used in the numerator and denominator to show an increase or decrease in either, or both, the abrasion resistance and work of rupture. Both signs positive indicated an acute angle with respect to the x-axis. A negative value indicated an obtuse angle.

m was calculated by the following method:

$m = \frac{y_1 - y}{x_1 - x}$, where y_1 = the y coordinate after treatment

y = the y coordinate before treatment

x_1 = the x coordinate after treatment

x = the x coordinate before treatment

Slope values of m:

When $m = \frac{0.000}{+1.000}$, abrasion resistance constant; work of rupture increased

$m = \frac{0.000}{-1.000}$, abrasion resistance constant; work of rupture decreased

$m < \frac{+1.000}{+1.000}$, greatest change in work of rupture; both increased

$m < \frac{+1.000}{-1.000}$, greatest change in work of rupture; work of rupture decreased and abrasion resistance increased

$m < \frac{-1.000}{+1.000}$, greatest change in work of rupture; work of rupture increased, abrasion resistance decreased

$m < \frac{-1.000}{-1.000}$, greatest change in work of rupture; both decreased

$m = \frac{+1.000}{+1.000}$, work of rupture and abrasion resistance equally affected, with an increase in both

$m = \frac{+1.000}{-1.000}$, both equally affected; abrasion resistance increased and work of rupture decreased

$m = \frac{-1.000}{+1.000}$, both equally affected; abrasion resistance decreased and work of rupture increased

$m = \frac{-1.000}{-1.000}$, both equally affected; both decreased

$m > \frac{+1.000}{+1.000}$, greatest change in abrasion resistance; both increased

$m > \frac{+1.000}{-1.000}$, greatest change in abrasion resistance; work of rupture decreased, abrasion resistance increased

$m > \frac{-1.000}{+1.000}$, greatest change in abrasion resistance; work of rupture increased, abrasion resistance decreased

$m > \frac{-1.000}{-1.000}$, greatest change in abrasion resistance; work of rupture decreased, abrasion resistance decreased

$m = \frac{+1.000}{0.000}$, or $+\infty$, abrasion resistance increased; no change in work of rupture

$m = \frac{-1.000}{0.000}$, or $-\infty$, abrasion resistance decreased; no change in work of rupture

The calculated slope values and an explanation of their significance to :he effects of various treatments on thread are discussed below.

Mercerization under tension caused no change in work of rupture but a lecrease in abrasion resistance; whereas, slack mercerization caused a decrease .n work of rupture but an increase in abrasion resistance. The slack mercerized hread increased in abrasion resistance by 49% while the thread mercerized under ension suffered a 25.7% loss of abrasion resistance. This comparison showed hat for mercerization alone, slack mercerization was better than tension ercerization.

When DMEU treatments were applied to the soft threads and left uncured, slope value of $\frac{-0.818}{-1.000}$ was obtained. Since this value was less than $\frac{-1.000}{-1.000}$, he work of rupture was affected more than the abrasion resistance; although oth decreased. When the soft DMEU treated thread was cured, a slope value of $\frac{0.000}{1.000}$ was obtained, indicating that the work of rupture decreased and the brasion resistance remained constant. When mercerized thread was treated with MEU and cured, a slope value of $\frac{+0.167}{-1.000}$ was obtained. The small positive value or abrasion resistance showed that it increased slightly, but not as much as the work of rupture decreased. In both cases (soft and mercerized) the work of rupture decreased as a result of the DMEU treatment; however, the soft thread suffered greatest loss in work of rupture.

The triazine treated soft thread had a slope value of $\frac{-0.423}{-1.000}$. The greatest decrease was in the work of rupture. When the treated thread was cured, a slope value of $\frac{+0.500}{+1.000}$ was obtained. Here the work of rupture increased more than the abrasion resistance. The opposite effect occurred when DMEU treated thread was cured.

When triazine was applied to mercerized thread and cured, a slope value of $\frac{+0.167}{-1.000}$ was calculated. This shows a decrease in work of rupture and a slight increase in abrasion resistance. When compared with the soft, triazine treated and cured thread, the mercerized version showed a decrease in work of rupture and an increase in abrasion resistance. The opposite effect occurred when untreated thread was mercerized.

Dixie Yarns mercerized thread treated with a delay cure resin treatment had a slope value of $\frac{-0.433}{-1.000}$. The work of rupture was affected by the delay cure treatment more than the abrasion resistance. When the treated thread was cured, a slope value of $\frac{-9.670}{-1.000}$ resulted. This showed clearly that curing of the delay cure resin treatment decreased the abrasion resistance of the thread greatly. The decrease in work of rupture (2%) was so small that it was disregarded.

When a second Dixie Yarns mercerized thread was treated with a moderate level of resin, a slope value of $\frac{-0.392}{-1.000}$ resulted. Since this value of the numerator was close to zero, the increase in abrasion resistance was considered insignificant; however, the decrease in work of rupture was significant. The addition of a softner caused a 26% decrease in the work of rupture.

When a special lubricant was added to the moderate level resin treated thread, work of rupture and abrasion resistance increased as indicated by the slope value of $\frac{+0.403}{+1.000}$. The lubricant increased the work of rupture more than the softner discussed above decreased it.

When a Dixie Yarns mercerized thread was treated with a minimum level of resin, a slope value of $\frac{+0.600}{-1.000}$ resulted. The work of rupture decreased more than the abrasion resistance increased. However, the minimum level of resin treatment did not decrease the work of rupture as much as did the moderate level of resin treatment. Also, abrasion resistance increased over that of the untreated version.

As mentioned earlier, slack mercerization increased the abrasion resistance and decreased the work of rupture. When treated with DMEU and cured, a slope value of $\frac{-0.708}{-1.000}$ was obtained. In this case, the slope value was not so important as the point representing the treatment when compared with the point representing the thread treated with DMEU and cured, but mercerized under tension. Both points were located less than one unit apart. For all practical purposes, these points were one and the same on the graph. Therefore, there was no gain by slack mercerization over tension mercerization when DMEU treatment was applied.

E. Evaluation of double needle sewing technique

During previous quarters the investigation of seam pucker was confined to seams made using the single needle sewing technique. Another possible variable to be considered was double needle sewing. This technique has considerable importance since it is common in the trade. However, it was anticipated that seam pucker would be a greater problem in double needle sewing. Earlier work showed that puckering even in seams two inches apart was somewhat additive, i.e, the puckering in one line of stitches caused distortion in the other line also.

Therefore, if the distance was reduced to 3/8 inch it was probable that puckering between the lines of stitching would be intensified.

Work on a double needle lockstitch machine has not been undertaken, but a number of samples were sewed on a Union Special Type 51500 BJ (2 needles and 2 loopers) machine which makes a 401 stitch. This machine sews two lines of stitches simultaneously, 3/8 inch apart. Theoretically, this type of stitch should be less susceptible to thread breaks than the standard 301 lockstitch. Several variations were tried using samples of the test fabrics and threads.

It was found that there was the same relative sewability among test threads and fabrics that had been observed with the single needle lockstitch machine. The initial appearance of all seams was satisfactory but the results upon laundering were unsatisfactory.

The conclusions drawn from this work are that double needle sewing intensifies the problem already present in single needle sewing. Further study of the contribution of each component to the total effect of puckering is needed before the results can be extrapolated to include better ways to sew double needle seams. No further work on double needle sewing is planned under this contract.

F. <u>Evaluation of SRRL slack mercerized, restretched, treated and untreated threads and Dixie Yarns threads Style Nos. 033-36-1 through 033-36-5</u>.

Two lots of special treated threads were submitted for evaluation this quarter. One lot was from the Southern Regional Research Laboratory (SRRL) in New Orleans; the other, from Dixie Yarns, Inc. The lot from SRRL consisted of two cones of Coats and Clark Wolf quality thread, Ticket No. 70/2, soft finish. A portion of each cone was slack mercerized (46") and restretched to its original length (53.8"); the remaining thread was held for control. The slack mercerized, restretched thread was divided into two portions. One portion was left untreated; the other was treated with 7% DMEU resin treatment and cured.

The lot from Dixie Yarns consisted of five cones of thread, Ticket No. 70/2, which were waxed with their standard plant finish. The style number and a description of the treatment on each are listed below:

Style No.	Treatment
033-36-1	Moderate level of resin
033-36-2	Same level of resin as 033-36-1 plus a polypropylene softner
033-36-3	Near minimum level of resin
033-36-4	Same level of resin as 033-36-1 plus a special lubricating agent
033-36-5	Control - same thread as above but with no resin treatment

These two lots of soft threads were evaluated by similar tests used in evaluating the original lot of test threads. In this way reliable comparisons could be made. Test procedures and results are described below.

1. Thread sewability

a. SRRL treated thread: It was expected that slack mercerization would cause an increase in thread strength, therefore, improving its ability to be sewed at high speeds. By being restretched to its original length, the thread would become more stable. After being treated with a minimum level of resin, the thread would be stablized with a slight decrease in strength and sewability.

The abrasion resistance vs. work of rupture method, as described earlier in this report (see Section C), was used in predetermining sewability of this lot of thread. Abrasion resistance and work of rupture tests were made on the thread using the method described in Quarterly Report 6, pages 20-21. The results of these tests plus breaking strength and elongation tests were recorded in TABLE I.

When abrasion resistance and work of rupture were plotted on the sewability graph (Figure 2), it was found that the unmercerized control thread and the slack mercerized, restretched, untreated thread fell in Zone 1, the zone of good sewability, while the resin treated version fell in Zone 3, the zone of poor sewability due to low abrasion resistance.

Actual sewability tests (see Quarterly Report 5, page 7) showed that the unmercerized control thread and the slack mercerized, restretched but untreated thread sewed well. The resin treated version sewed with excessive breakage. However, it did sew better than the original resin treated threads used in this research.

b. Dixie Yarns special treated threads: It was anticipated that by using moderate and minimum level resin treatments on mercerized thread, the thread strength and sewability would not be destroyed by the resin. The minimum level resin treatment should cause the least amount of thread deterioration. By adding polypropylene as a softner and a special thread lubricant, the slight deterioration of the fiber by the resin should be somewhat masked and the sewability improved.

TABLE II contains the results of breaking strength, elongation, work of rupture and abrasion resistance for these threads. When the abrasion resistance and work of rupture were plotted on the sewability graph (Figure 2), it was found that all threads fell in the zone of good sewability except the thread treated with moderate level of resin plus a polypropylene softner. This thread fell in Zone 2, low work of rupture. The moderate level resin treated thread without any additional finish fell in the grey zone, Zone 5.

When these threads were sewed, it was found that all versions were sewable to a commercially acceptable degree except the version with the polypropylene softner added.

2. Measurement of thread stability

Earlier work showed that mercerized threads have better stability before and after washing than soft finish threads, and that resin treatments increase this stability even more. The increase in stability results in less likelihood of seam pucker. Because slack mercerization and restretching caused an increase

TABLE II

AVERAGE BREAKING STRENGTH, ELONGATION, WORK OF RUPTURE, ABRASION RESISTANCE AND SEWABILITY OF SRRL SLACK MERCERIZED, RESTRETCHED, TREATED AND UNTREATED THREADS AND DIXIE YARNS THREADS, STYLE NOS. 033-36-1 THROUGH 033-36-5

Thread No.	Breaking strength (lbs.)	Elongation (%)	Work of rupture (lb.in.)	Abrasion resistance (cycles)	Sewability
SRRL threads*					
Control 1	1.67	8.0	53.6		will sew
Control 2	1.68	6.2	47.4	11.3	will sew
Slack merc.1	1.62	6.9	48.8	16.8	will sew
Slack merc.2	1.46	5.7	31.0	4.2	will not sew
Dixie Yarns threads**					
033-36-1	1.63	3.8	31.4	9.0	will sew
033-36-2	1.43	3.6	28.2	9.8	will not sew
033-36-3	1.77	4.6	37.6	15.4	will sew
033-36-4	1.68	4.8	42.7	13.6	will sew
033-36-5	1.79	4.2	41.6	18.0	will sew

* SRRL threads:

Control 1 - Coats and Clark Wolf quality thread, TKT 70/2 soft.
Control 2 - Coats and Clark Wolf quality thread, TKT 70/2 soft.
Slack merc. 1 - Same thread as control but slack mercerized and restretched
Slack merc. 2 - Same thread as control but slack mercerized, restretched and treated with 7% DMEU and cured.

** Dixie Yarns threads:

033-36-1 - Moderate level of resin
033-36-2 - Same as 033-36-1 plus polypropylene softner
033-36-3 - Minimum level resin
033-36-4 - Same as 033-36-1 plus special lubricating agent
033-36-5 - Control, Ticket No. 70/2 mercerized, standard wax finish

in fabric stability, it was expected that slack mercerization and restretching would cause an increase in the stability of sewing thread, also. Resin treatment was expected to add even more stability. In the lot of Dixie Yarns thread, the degree of stability was expected to be in proportion to the amount of resin applied. Therefore, threads with moderate level resin application should cause more intense seam puckering than the thread with minimum level resin treatment. The addition of softners and lubrication agents was not expected to affect the stability of the thread.

The technique developed by Dorkin and Chamberlain for measuring extension and contraction was used to determine the stability of these test threads. Results are recorded on TABLE III. Results obtained on other test threads and details of the technique were reported in Quarterly Report 3, pages 8-9 and Quarterly Report 6, pages 19-20.

These results show that both the SRRL threads, soft and slack mercerized, treated and untreated have lower stability (higher percentages of extension (A) and contraction (B) than did comparable threads tested earlier.) When these threads were actually sewed, the samples were slightly puckered before washing, but after washing they were puckered severely.

The lot of Dixie Yarns threads also showed low stability. Percentage extension for these threads was considerably lower than for other test threads; however, percentage contraction was much higher. When these threads were sewed, the samples showed little puckering before washing. After washing the samples were puckered severely.

3. Determination of actual thread size

A toolmaker's microscope with microcaliper was used to measure the diameter of each thread (see Quarterly Report 5, page 11, and Quarterly Report 6, page 17). The results were as follows:

Thread Type	Diameter in mm.
SRRL threads	
Control 1	0.2715
Slack mercerized 1	0.2495
Slack mercerized 2	0.2636
Dixie Yarns threads	
033-36-1	0.2325
033-36-2	0.2437
033-36-3	0.2401
033-36-4	0.2378
033-36-5	0.2653

It was found that SRRL slack mercerized, restretched threads were smaller in diameter than the unmercerized version, but when resin treated, the thread diameter increased. In the lot of Dixie Yarns threads, the diameter decreased after resin treatment.

TABLE III

CONTRACTION AND EXTENSION OF SRRL SLACK MERCERIZED, RESTRETCHED, TREATED AND UNTREATED THREADS AND DIXIE YARNS THREADS, STYLE NOS. 033-36-1 THROUGH 033-36-5

Thread No.	Extension (A) %	Contraction (B) %	A + B %
SRRL threads			
Control 1	1.68	2.46	4.14
Slack merc. 1	1.57	2.23	2.80
Slack merc. 2	2.13	1.80	3.93
Dixie Yarns threads			
033-36-1	0.69	3.56	4.25
033-36-2	0.22	4.16	4.38
033-36-3	0.89	3.80	4.69
033-36-4	1.00	4.01	5.01
033-36-5	1.23	2.46	3.69

(A) Extension under 100 g. load(%) =

$$\frac{\text{length under load - length under hook}}{\text{length under hook}} \times 100$$

(B) Contraction after 5 min. boiling (%) =

$$\frac{\text{length under hook - length after boiling}}{\text{length under hook}} \times 100$$

These data were used in calculating the maximum stitch length for given fabrics as described in the paragraph below.

4. Calculation of the optimum stitch length

The number of stitches that can be made in one inch of a fabric without causing yarn jamming depends upon the size of the sewing thread and the available space between the yarns in the fabric. If a thread is larger than the interstices, the yarns between the interlock points in the seam will be forced to move out of a common plane resulting in yarn jamming. This jamming will appear to the observer as seam pucker. An analysis of this point is not commonly used in the garment industry, but it could be used as a method of reducing seam pucker.

The technique for calculating the maximum number of stitches per inch that can be sewed in a fabric was described in detail in Quarterly Report 5, pages 11-12. This technique was used in calculating the maximum number of stiches per inch that can be sewed in Belfast, Permafresh and untreated print cloth without causing yarn jamming when sewed with SRRL slack mercerized, restretched, treated and untreated thread and Dixie Yarns special treated thread. Results of these calculations were recorded in TABLE IV.

These calculations show that all test threads can be sewed at 10 stitches per inch in the test fabrics without causing yarn jamming, and all except SRRL control thread can be sewed at 12 stitches per inch. Conversely, none of the threads would sew at 16 stitches per inch without overcrowding the yarns.

TABLE IV

OPTIMUM NUMBER OF STITCHES PER INCH USING SRRL SLACK MERCERIZED, RESTRETCHED, TREATED AND UNTREATED THREADS AND DIXIE YARNS THREADS, STYLE NOS. 033-36-1 THROUGH 033-36-5

	Number of SPI	10	12	14	16	Max. No. of SPI
	Theoretical Length of stitch (mm.)	2.540	2.117	1.814	1.588	
	Untreated print cloth (warpwise)					
	033-36-1	2.272	2.010	1.822*	1.683*	13.8
	033-36-2	2.306	2.034	1.856*	1.715*	13.2
	033-36-3	2.295	2.032	1.845*	1.704*	13.4
	033-36-4	2.288	2.026	1.838*	1.698*	13.5
	033-36-5	2.370	2.108	1.921*	1.780*	12.1
	Control 1	2.389	2.127*	1.939*	1.799*	11.9
	Slack merc. 1	2.323	2.061	1.873*	1.733*	12.9
	Slack merc. 2	2.365	2.103	1.915*	1.775*	12.2
	Belfast print cloth (warpwise)					
Space occupied by yarns and thread per stitch	033-36-1	2.140	1.900	1.728	1.599*	15.7
	033-36-2	2.174	1.933	1.762	1.633*	15.0
	033-36-3	2.163	1.922	1.751	1.622*	15.2
	033-36-4	2.156	1.916	1.744	1.615*	15.4
	033-36-5	2.238	1.998	1.826*	1.698*	13.8
	Control 1	2.257	2.017	1.845*	1.716*	13.5
	Slack merc. 1	2.191	1.951	1.779	1.650*	14.7
	Slack merc. 2	2.233	1.993	1.821*	1.692*	13.9
	Permafresh print cloth (warpwise)					
	033-36-1	2.200	1.949	1.771	1.636*	14.9
	033-36-2	2.233	1.983	1.804	1.670*	14.2
	033-36-3	2.223	1.972	1.793	1.659*	14.4
	033-36-4	2.216	1.965	1.786	1.652*	14.5
	033-36-5	2.298	2.048	1.869*	1.735*	13.0
	Control 1	2.317	2.066	1.888*	1.753*	12.7
	Slack merc. 1	2.251	2.001	1.822*	1.688*	13.9
	Slack merc. 2	2.293	2.043	1.864*	1.730*	13.1

* Jamming of yarns will cause yarn movement out of a common plane.

III. FUTURE PLANS

The following work remains to be completed in order to carry out the proposed program as planned:

1. Determination of the nature of the distribution of resin on treated threads, i.e., on surface, partially attached chemically, fully attached chemically or combinations of all states.
2. Relation of distribution of resin to observed sewability of the threads.
3. Analysis of the physical characteristics and sewability of the following types of thread now being prepared in the laboratory:
    a. Coats and Clark Laboratory - film forming agents.
    b. Coats and Clark Laboratory - semi-durable swelling agents.
    c. SRRL - slack mercerized and restretched.
4. Preparation of a paper on this research to be read on April 21st at New Orleans.
5. Preparation of proposals for follow on research.
6. Further analysis of high speed motion pictures taken of sewing under laboratory conditions.
7. Further improvements on the photometric measuring device.
8. Further field trips to operating sewing plants to observe and evaluate results now being obtained when sewing with cotton thread on resin treated 100% cotton fabrics.
10. Comparison of these observations to the results obtained on 100% cotton wash and wear fabrics in the laboratory.

QUARTERLY REPORT 8

PROJECT A-786

PHYSICS OF SEAM PUCKER

JAMES L. TAYLOR and FRANK J. CLARKE

Contract 12-14-100-719(72)

15 MARCH 1966 to 14 JUNE 1966

Prepared for
U. S. Department of Agriculture
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New Orleans, Louisiana

1966

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

GEORGIA INSTITUTE OF TECHNOLOGY
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Atlanta, Georgia

QUARTERLY REPORT 8

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JAMES L. TAYLOR
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SOUTHERN UTILIZATION RESEARCH AND DEVELOPMENT DIVISION
NEW ORLEANS, LOUISIANA

ABSTRACT

This is the eighth quarterly report on research undertaken under this project. All experimental work has been completed. A paper was presented during the Sixth Cotton Utilization Research Conference briefly summarizing the investigations to date. During this quarter the possibilities of semi-durable swelling agents, film forming agents, slack mercerization with restretching and various thread lubricants in improving the performance of cotton thread were evaluated. None of these approaches was appreciably better in after-laundering appearance than the resin treatments examined earlier. The variations in performance of the resin treated threads led to an investigation of the disposition of the resin on or in the thread. It was found that the best performance was obtained from a thread in which the resin was wholly within the lumen. Colored slides illustrating this point have been provided to the sponsor. Further interpretation of the data on thread fatigue was undertaken and is reported here. Another study was made relating the resistance of the yarn systems to sewing and its effect on soft and mercerized threads. This study partially explained the failure of mercerized threads to give anticipated good after-laundering appearance. It is planned to submit a final report correlating data obtained on all research under this contract. An extension for this research into the area of all-cotton durable press and other recent developments has been recommended to the sponsor.

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I. INTRODUCTION

A. General

Emphasis was placed this quarter on completing all research specified in the contract for this project. Work included an evaluation of threads treated with semi-durable swelling agents and film forming agents. These treatments did not impair the satisfactory sewability of the threads, except for Triton B which severely degraded the thread; however, these treatments did not impart characteristics to the threads which would reduce their tendency to cause seam pucker.

Based on previous work, a study was made to correlate the relationship of the resistance of yarn systems to deformation by tension on the thread during sewing and contraction of the thread and cloth after sewing. This provided a better understanding of the tendency of seams sewed with mercerized threads, which are satisfactory before washing, to become as unsatisfactory after washing as do seams sewed with soft threads.

New work included an investigation of the disposition of resins on thread to explain the variations in physical characteristics among threads treated with various resins. Threads found to have the resin located totally within the fiber lumens had better sewability than threads with resin coating the surface of the thread or fibers.

A notice of invention has been filed on the photometric method of evaluating seam pucker.

B. Conferences

A paper on this project was presented at the Sixth Cotton Utilization

Research Conference in New Orleans on April 20, 1966. Copies of this paper can be secured through SRRL. Considerable interest has been shown in this research as a result of the presentation. A large number of requests from industry for copies of this paper have been forwarded to the SRRL.

Other conferences have been held with Miss Lillian Knight, Textile Engineer, The Singer Company, Denville, New Jersey; Mr. Charles Lewis, Technical Adivsory Committee, AAMA; Mr. David H. Fields, Director of Research, The American Thread Company, Willimantic, Connecticut; Mr. Clett Cooper, Chief Mechanic, Arrow Shirt Company, Atlanta, Georgia; Mr. Howard Seitz, Chemist, Dixie Yarns, Inc., Chattanooga, Tennessee; and Mr. I. Stavis and Mr. H. J. Leavitt, Koratron Company, San Francisco, California.

Mr. Paul Hilley, Division Manager, Coats & Clark, Inc., Mr. Frank J. Clarke and Miss Zona Thrift of the project team discussed this research at the Home Economics in Business luncheon in Atlanta on April 18.

II. RESEARCH PERFORMED

A. A study of the disposition of resins on thread

1. Background

One approach to improving the compatability of cotton thread and wash-wear treated fabrics was through the application of resin to the thread.

Earlier work on this project established that various resin treatments produced different results on similar threads. Generally, the threads with high breaking strength and high abrasion resistance sewed satisfactorily. A decrease in breaking strength or abrasion resistance appeared to reduce sewability in many cases.

This did not occur uniformly throughout the samples evaluated. Some threads with low breaking strength and high abrasion resistance sewed satisfactorily. Likewise, some threads with high breaking strength and low abrasion resistance would not sew without excessive breaking.

It was hypothesized that this variation was related to the location of the resin on the thread and fibers. If resins located on the surface of the fibers act as abrading agents, they can be expected to cause a decrease in abrasion resistance and breaking strength of the thread. During breaking, the fibers coated with resin slip past each other. In slipping, they cause abrasion within the thread thus lowering both the abrasion resistance and the breaking strength of the thread.

In threads where the resins are located within the fibers, the resins are less likely to act as an abrading agent until the fibers are abraded enough to expose the resin. In this case the threads should have higher breaking strength and higher abrasion resistance.

This was established, see Table I, by the use of an indicator followed by photomicroscopic analysis.

Anthraquinone Blue BN, an acid dye that stains resins blue but does not affect cellulose, was chosen as an indicator of the location of the resin.

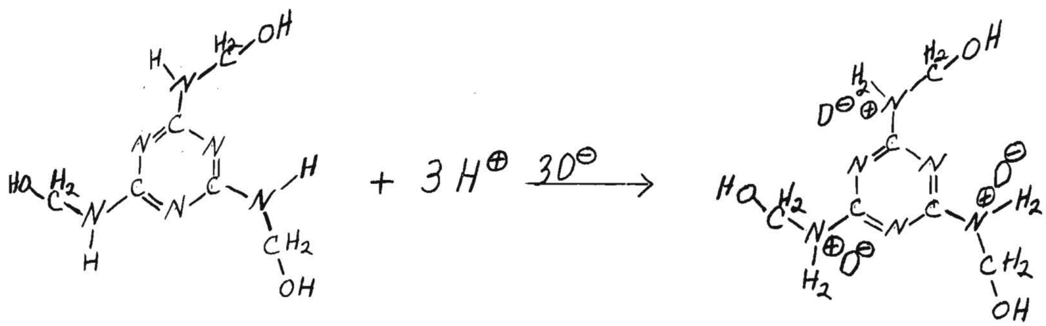
The following threads were selected because they displayed the variations which were being examined:

Code No.	Thread Description	Observed Sewability
1	Mercerized triazine, cured	Fair
2	Soft triazine, uncured	Poor
3	Soft triazine, cured	Poor
4	Soft DMEU, cured	Poor
5	Mercerized DMEU, cured	Poor
6	Mercerized untreated	Good
7	Soft DMEU, uncured	Poor
8	Soft untreated	Good
9	031-67-3 untreated	Good
10	033-36-1 moderate level unknown resin	Good
11	033-36-3 minimum level unknown resin	Good
12	033-36-5 control	Good

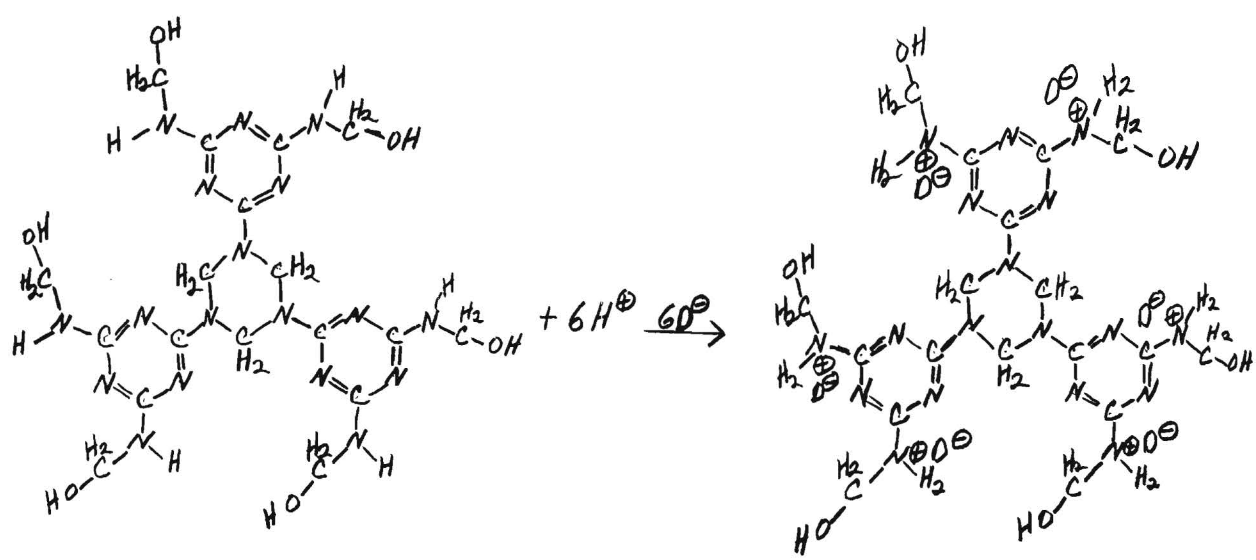
2. Theoretical reactions of the dye to resins

The three types of cross-linking resins examined were DMEU, triazine and an unknown resin. It was anticipated that Anthraquinone Blue BN would react with the different resins with the following reactions:

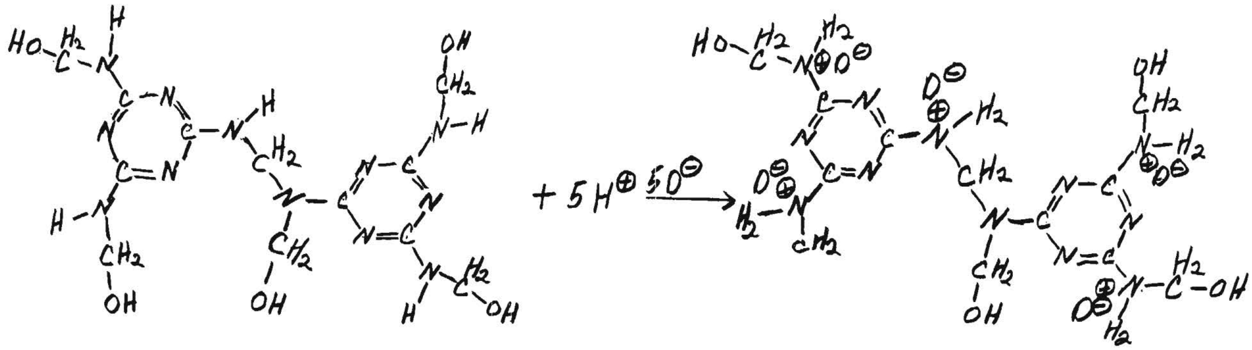
Pre-condensation reaction of triazine with acid dye, D^-, is



Cyclic condensation reaction of triazine with the acid dye, D^-, is



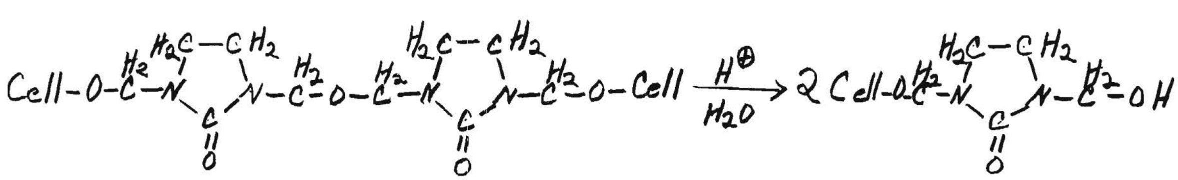
Linear condensation reaction of <u>triazine</u> with the acid dye, D^-, is



The reactions shown above are for uncured and cured triazine treated threads. The reactions probably form a network that is three dimensional, not two dimensional as illustrated.

Ideally, DMEU cross-links with cellulose and does not provide sites for the acid dye, D^-, to attach. However, this does not appear to be the actual reaction. If there is any acid left after the curing process, the following series[1] of reactions occur:

1.



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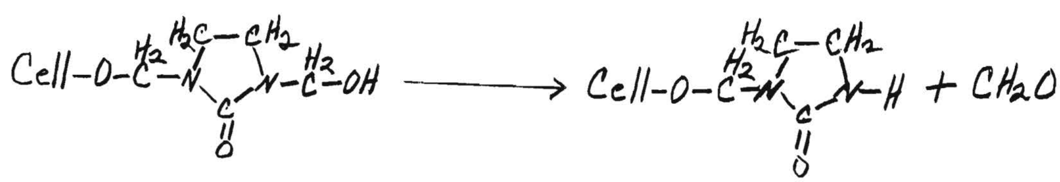
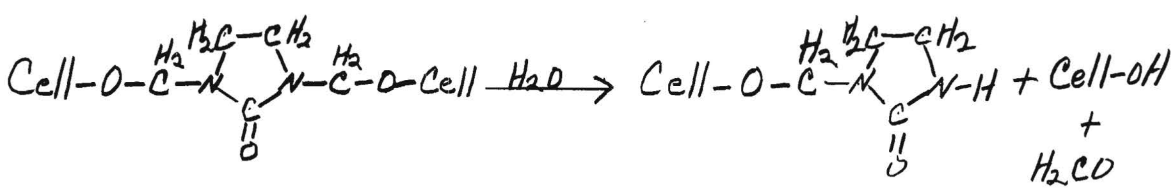
[1] Based on reactions proposed by A. R. Smith (Am. Dye Rep., April 20, 1959). However, another series may be written as prepared by Hugh H. Mosher (Text. Res. J., January, 1959).

2.



3.

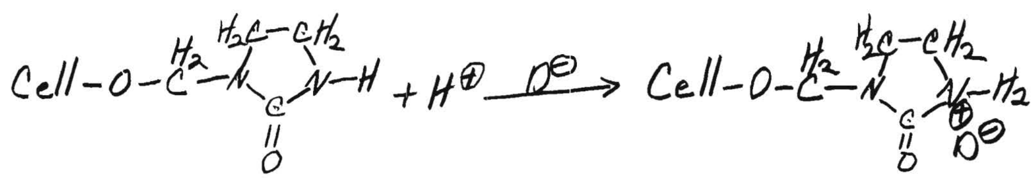


These reactions leave a secondary amine site for protonation. Then the dye attaches by electrostatic force to the protonated site.

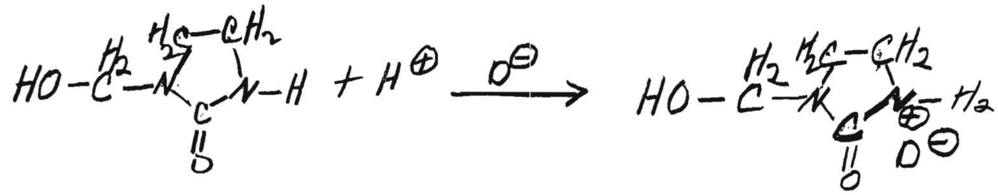
The question brought to mind at this point is why did the acid not attach in the tertiary form? The answer lies in the basicity of the two types of amines. The tertiary amine is a poor base, thus it is not likely to be protonated. The secondary amine that is formed after hydrolysis is a fairly good base and will be protonated. This condition possibly occurred during the eighteen months the DMEU treated threads were stored, before being evaluated. This could have caused their poor performance.

The addition of the acetic acid hastened the reaction from the second phase to the third.

The following reaction is the one most likely to have occurred when the acid dye, D^-, was added to the protonated DMEU resin:



The following reaction shows the reaction of uncured DMEU with the acid dye, D^-:



As can be seen from the illustrations, there is only one dye molecule per resin chain for DMEU as compared with five for the linear condensation of triazine, three for the uncured triazine and six for the cylic condensation of triazine.

So it was expected that the indicator would show the presence of resin in all types of treatment. The intensity of color would vary, with DMEU threads showing less stain than triazine threads.

3. <u>Test procedure for locating the resin disposition on thread</u>

A 65 yard skein of each thread was selected for this test. The lubricants applied to the thread during manufacturing were removed with a solvent (Trichloroethylene, Bp. = 86°C) in a Soxhlet apparatus. The solvent was cycled four times for optimum results.

A portion of each thread with the lubricant removed was tested for breaking strength, elongation, work of rupture and abrasion resistance. A comparison of these results with the results of similar tests on each thread before removal of the lubricants can be found in Table I.

Approximately 0.09 gram samples of each thread with the lubricant removed were used for determining the location of the resin by staining. Each thread was stained according to the following procedure:

a. A 0.25 percent owf solution of Anthraquinone Blue BN was prepared containing one drop of glacial acetic acid per one milliliter of solution. This solution was used to prepare a bath for immersion of each test skein. Each skein remained in this bath for four hours at room temperature (68°F) after which it was removed.

b. Each thread was washed thoroughly with cold water and air dried at room temperature for twenty-four hours and then examined.

c. Upon examination, it was found that all of the threads except those treated with DMEU had been stained by the indicator sufficiently for photographing. The DMEU threads were replaced in the same dye bath for an additional twenty-four hours. At the end of this period they too were sufficiently stained by the indicator.

4. Evaluation of stained threads

The stained skeins were unwound and examined at 110x to determine whether the dye indicated the presence of resin.

Cross-sections of selected regions of each thread were chosen and made into 2" x 2" color slides for more complete analysis. Results of these observations are recorded in Table I.

Table I

DISPOSITION OF RESINS ON SELECTED THREADS

Code No.	Surface staining	Cross-section staining
1	Uneven staining	Stain on surface of thread and fibers
2	Deep, even staining	Stain on surface of thread and fibers; half of thread deeply stained
3	Uneven staining	Light to heavy stain on surface of thread and fibers
4	Very light, even staining	Light stain on surface of fibers
5	Very light, even staining	Very light stain on surface of fibers
6	Not stained	Not stained
7	Very light, even staining	Very light stain on surface of fibers
8	Not stained	Not stained
9	Light, even staining	Light stain within lumen
10	Light, even staining	Stain within and around lumen
11	Light, even staining	Stain within and around lumen

Table I (Continued)

Code No.	Surface staining	Cross-section staining
12	Light, even staining	Stain within lumen and along length of fiber

Visual examination of thread no. 2, an uncured triazine treated thread, indicated a uniform distribution of resin on the surface of the fibers.

Threads 1 and 3, cured triazine treated threads, were stained irregularly in sections. Portions of these threads were heavily stained, others were lightly stained, and others were unstained. Since both of these threads had been treated with triazine, a homopolymer, and then cured this performance was unexpected.

According to Marsh (Crease Resisting Fabrics, page 264) the depth of the stain was inversely proportional to the hardness of the cure of the resin. Thus, a hard cured portion showed the least intensity of staining, and conversely.

Since it was known from visual examination of thread no. 2 that the triazine had been applied uniformly to the surface of the thread, it was concluded that extensive migration of the resin had occurred during the curing process.

Threads 4 and 5, which had been treated and cured with DMEU, displayed the same light, uniform staining as thread 7, and uncured DMEU thread. This had been anticipated from the chemical structure of this resin, a cross-linking agent. No evidence of migration of resin upon curing was observed.

Threads 6 and 8, which were untreated, did not stain.

Threads 10 and 11, which contained moderate and minimum levels respectively of an unknown resin, stained lightly and uniformly.

Threads 9 and 12, supposedly untreated, actually stained slightly. This observation is being examined by the manufacturer and the explanation is not available at present.

The structure of the resin used on threads 10, 11, and possibly 9 and 12, appeared to be similar to DMEU.

Twenty-three color slides illustrating the variations observed in this study have been forwarded to the sponsor.

Threads 1, 2, 3, 4, 5, and 7 were manufactured about eighteen months ago. In each of these samples, the heaviest concentration of resin was on the surface of the thread. Individual fibers were coated rather than penetrated. This coating was not uniform but was heavier around the outer edge of the thread. Very little resin was found near the center of the thread (Refer to Slides 1 through 12 and 14).

The resin in threads 10 and 11, which were manufactured about twelve months ago, was wholly within the lumen of the cotton fibers. This is clearly evident from an examination of Slide 23, a cross-section in which a single fiber was cut longitudinally while other fibers were being cut laterally. This fiber was stained along the entire length of its lumen and at no other point.

There was greater uniformity of disposition of the resin on threads 10 and 11 than on the original group. This may relate to the difference in resin or to the method of application or both. The original group, threads 1, 2, 3, 4, 5, and 7, were treated and cured in skein form while threads 10 and 11 were treated and cured in continuous form. The original group contained purely experimental threads. Threads 10 and 11 are versions of a commercial thread.

B. Correlation of the location of resins on threads and their physical characteristics

1. Experimental technique

A separate study was made of the effect of resins, both uncured and cured, on the physical characteristics of thread. Samples of untreated thread were tested for breaking strength, elongation, work of rupture, and abrasion resistance. These results are tabulated in Table II.

Samples of each corresponding treated thread were then stripped of their lubricants. The resin present on each thread was removed by the technique specified in AATCC Method 94-1965T. Tests with Anthraquinone Blue BN indicated that all resin had been removed from the threads.

These threads were subjected to the same tests as their untreated versions. The results are shown in Table II.

2. Interpretation of data

In interpreting the data in Table II, caution must be exercised. There was reason to believe that the hydrolysis of the resin may have also damaged the thread. It cannot be stated how much of the decrease in strength of the treated threads from their untreated versions was attributable to action of the resin alone. Further study of this point was warranted but was beyond the scope of this contract.

For the mercerized triazine cured thread (#1), the elongation increased with the removal of the lubricant and the resin; however, the breaking strength and abrasion resistance decreased with the removal of both.

Table II

PHYSICAL CHARACTERISTICS OF SELECTED RESIN TREATED THREADS WITH LUBRICANTS APPLIED, WITH LUBRICANTS REMOVED AND WITH RESINS REMOVED

Thread	Thread	Before Stripping Lub.				Before Hydrolysis				Pure Cotton Thread			
Treatment	Number	ELON	B.S.	WOR	AR	ELON	B.S.	WOR	AR	ELON	B.S.	WOR	AR
Merc.triazine cured	(1)	5.0	1.76	34.6	8.8	5.9	1.44	33.6	1.0	8.0	0.91	30.8	0-1
Soft triazine uncured	(2)	5.9	1.24	26.4	4.5	7.0	1.26	43.0	1.6	5.4	0.96	21.8	0-1
Soft triazine cured	(3)	6.3	1.42	36.8	9.7	8.3	1.73	51.6	2.0	6.3	0.55	12.2	0-1
Soft DMEU cured	(4)	6.0	1.26	29.0	3.3	7.2	1.14	40.6	2.2	5.3	0.08	13.2	0-1
Merc. DMEU cured	(5)	4.5	1.66	30.8	4.5	4.9	1.42	32.0	1.3	5.7	0.97	21.4	0-1
Merc. untreated*	(6)	5.2	1.96	40.6	7.8	6.4	1.60	45.6	0-1	5.7	1.10	23.8	0-1
Soft DMEU uncured	(7)	6.2	1.27	31.8	3.3	6.9	1.11	36.0	0.8	6.9	0.70	19.2	0-1
Soft untreated	(8)	7.2	1.48	40.6	10.5	8.2	1.34	51.6	1.2	7.9	0.83	25.4	0-1
031-67-3 untreated*	(9)	4.8	1.60	41.0	18.2	6.4	1.71	50.6	3.5	5.3	0.97	21.0	0-1
033-36-1 mod. level	(10)	3.8	1.63	31.4	9.0	4.8	1.54	34.0	2.6	7.4	0.69	19.2	0-1
033-36-3 min. level	(11)	4.6	1.77	37.6	15.4	4.6	1.56	39.4	3.5	6.5	1.09	27.8	0-1
033-36-5* control	(12)	4.2	1.79	41.6	13.0	6.6	1.78	59.2	3.0	7.3	1.25	36.8	0-1

* Threads not treated with resins; Elon. = percentage elongation; B.S. = breaking strength in lbs. WOR = work of rupture in lb. in.; AR = abrasion resistance in cycles.

The removal of the resin was the most drastic step. The work of rupture remained almost constant with one factor balancing another.

When the soft, triazine uncured thread (#2) was stripped of its lubricant, the elongation increased with the breaking strength remaining constant. The work of rupture increased due to the increase in elongation properties. The abrasion resistance decreased as a result of the removal of the lubricant. When the resin was removed the abrasion resistance dropped to an extremely low level.

When this triazine treated thread was cured (#3), the initial elongation, breaking strength, work of rupture, and abrasion resistance were higher than the initial values of the uncured version. This trend continued after removal of the lubricant. The removal of the resin caused the work of rupture and breaking strength of the cured version to drop below those of the uncured thread. The elongation of the cured thread was higher than the uncured. Both versions showed the same resistance to abrasion.

Obviously, the triazine resin, when cured on the soft thread produced a higher quality thread than on mercerized thread although there was some question about the uniformity of the curing.

When the DMEU treated, uncured and cured soft threads were compared, the initial values of both were almost equal. The DMEU acted as a cross-linking agent with the cellulose initially and should have been readily removable by hydrolysis whether in uncured or cured form. No physical change in the cellulose should have occurred during curing. But the cured version was slightly better than the uncured version after removal of the lubricant and after removal of the resin.

This indicated that the resin upon curing had changed the properties of the cotton slightly because they should be equal after removal of the resin. Two other theories could be drawn. The hydrolysis step may have clipped some of the cellulose chains in the uncured version. It seemed more likely that there could have been an incomplete removal of the resin because it is of the cross-linking type and not as susceptible to clipping as the homopolymer type resin. The length of the resin chain may have been destroyed but enough remained to preserve most of the original characteristics.

The mercerized DMEU cured was compared to the mercerized triazine cured (previously discussed). In all three sets of data, DMEU was poorer than triazine, except after removal of the resin; the elongation was smaller and the breaking strength was higher than those values for triazine.

When the mercerized untreated thread was compared to the soft untreated, the soft possessed lower values than the mercerized except after the hydrolysis treatment where the elongation was smaller and breaking strength was higher.

Dixie Yarns thread 031-67-3 cannot be compared to the triazine and DMEU threads because it represents a different lot with possibly a different resin treatment. However, one can easily see why this thread would sew. The thread lubricant used appeared to account for its ability to sew. This thread lost 80.8 percent of its abrasion resistance by removal of the lubricant. The breaking strength increased along with elongation and work of rupture. After hydrolysis, all four values decreased.

Initially, the control thread 033-36-5 possessed the highest work of rupture, but its elongation, breaking strength, and abrasion resistance were almost the same as the minimum level treated thread 033-36-3. Thread 033-36-1 with a moderate amount of resin possessed the lowest values initially. After removal of the lubricant, threads 033-36-1 and 033-36-3 displayed similar characteristics. However, after hydrolysis, 033-36-3 and 033-36-5 were closer in all values except for elongation.

C. Correlation between the resistance of the yarn systems to the tension on thread during sewing and the contraction of the thread and cloth in the seam

1. Background

In previous reports, the effect of washing on the fabrics was mentioned (Quarterly Report 5, page 28), the characteristic changes in sewing threads after washing was shown (Quarterly Report 4, page 3, Table III on page 7, and page 14), and some physical properties of sewing threads and dimensional stability of fabrics were discussed. These three relationships may not be explained readily. They are observed in the resistance of the yarn systems to the tension of the threads, in the formation of the seam, and in the contraction or extension of thread on cloth before and after washing.

2. Resistance of yarn systems to thread tension

It was noted that the tension on the thread during sewing extended the thread before a stitch was formed. After a stitch was formed as a part of the seam, the yarns in the cloth prevented the sewing thread from contracting to its original length. To some extent, the thread remained extended in the seam, but part of this extension of the sewing thread was recovered upon releasing the tension as soon as a stitch was formed. To form the next stitch, the thread was extended even greater by the movement of the cloth in the opposite direction caused by feeding action of the machine.

Further study of the data shown in Table III, page 7 of Quarterly Report 4 showed that it was impossible to determine how much of the change in thread length after sewing was attributable to stretch induced during sewing and how much recovered immediately after removal from the seam.

Data on the number of stitches that could be sewed with 90 cm of thread had value in this study. It was found that when this amount of thread was sewed at 5000 RPM making 12 stitches per inch, the number of stitches formed varied with the construction of the fabric. This should not have occurred if the various threads and fabrics were identical in their properties.

3. Formation of the seam

The samples of three fabrics sewed in the warp direction differed in the number of stitches that were sewed from 90 cm of thread. This variation occurred when using both soft and mercerized threads. When sewing print cloth, the Permafresh treated samples sewed fewer stitches per 90 cm of thread than either the Belfast or untreated print cloth samples. This also meant that it required the most thread to form a single stitch in the Permafresh print cloth. This could be explained as being caused by:

1) less extension of the thread during sewing Permafresh print cloth, or
2) less deformation of the yarn systems, or greater resistance to the tension of the sewing thread, or
3) a combination of both factors.

When the type of thread was held constant, Permafresh print cloth showed excellent dimensional stability, while the yarn systems of the untreated print cloth were deformed by the tension created by the same thread.

When the fabric was held constant and the type of thread varied, the mercerized thread extended more than the soft thread during sewing. This was true despite the lower percentage of elongation by the mercerized thread under constant-rate loading.

This could be explained in terms of the tension on the thread during sewing. This tension could have extended the thread further beyond the primary or secondary creep point. This was more severe in the mercerized threads which meant that it required a longer time for the thread to contract to its original length. In some cases where extension had occurred beyond the secondary creep point, the thread remained longer than its original length.

The extension of the mercerized thread permitted less tension on the yarn systems which meant less tendency to induce pucker. This appeared to be a part of the explanation of why mercerized thread caused less pucker than soft thread before laundering.

The mercerized threads had lower elastic limits and yield points than the soft threads. This was determined through experiments conducted on mercerized thread using the sonic fatigue device with a 6 inch span.

The thread was attached to the hook of the device and extended without tension for 6 inches. A point 100 mm from the hook was marked on the thread. The thread was then clamped and the device run for 10 seconds at 83 cycles per second. The clamp was then loosened, the thread was straightened under a 2 gram load and reclamped. This cycle was repeated five times after which the cumulative extension was measured. Twenty specimens of each thread were measured by this technique with the results shown in Table III.

This measurement of cumulative extension of both soft and mercerized thread under a vibrating load was considered to be a close approximation of that which occurred in actual sewing. It was found that the amount of cumu

Table III

CUMULATIVE EXTENSION OF THREAD (mm)

Soft thread (70/2) Sample					Mercerized thread (70/2)			
1	0.6	0.9	0.5	0.5	1.0	1.0	0.8	0.8
2	0.5	0.8	0.6	0.7	1.0	1.0	0.5	0.7
3	1.0	1.0	1.0	1.0	0.8	1.0	1.0	1.7
4	0.7	0.8	0.6	0.7	0.7	0.9	0.9	0.8
5	0.7	0.7	0.4	0.6	1.0	0.8	1.0	1.0
Mean = 0.72 mm					0.88 mm			

lative extension of soft thread was significantly smaller than that of mercerized thread even at a 1 percent significance level.

4. Contraction and extension of thread and the cloth before and after washing

A determination of the correlation between the resistance of the yarn to the tension on the thread and the contraction of the thread and cloth after washing was made using the following technique:

Six 5" x 24" samples, each of Belfast, Permafresh and untreated broad cloth were folded in half and sewed with 70/2 soft and mercerized thread in the warp direction at 12 SPI and 5000 RPM. A 14 inch segment of each seam was selected and marked. The number of stitches in each segment was counted and recorded in Table IV.

The number of stitches formed in the untreated fabric closely approximated the theoretical total of 14" x 12 SPI, or 168 stitches. Mercerized thread formed a larger number of stitches than the theoretical total and

Table IV

A COMPARISON OF THE NUMBER OF STITCHES IN 14 INCH SEAMS
WITH THE THEORETICAL TOTAL OF 168 STITCHES (12 SPI x 14")

70/2 Soft Thread			70/2 Merc. Thread		
Belfast	Permafresh	Untreated	Belfast	Permafresh	Untreated
172.0	176.0	170.0	172.0	172.0	169.0
172.0	175.0	169.0	172.0	171.0	169.0
173.0	175.0	168.0	172.0	171.0	169.0
173.0	174.5	169.0	170.5	172.0	168.0
173.5	174.0	168.0	172.0	173.0	169.0
174.0	173.0	169.0	172.5	172.0	170.0
Mean 172.9	174.6	168.8	171.8	171.8	169.0

soft thread, the largest number of stitches.

It was noted that there was a greater variation in the number of stitches in the samples sewed with soft thread than in the samples sewed with mercerized thread. This can be explained by assuming the mercerized thread was less elastic than the soft thread. The tension exerted during sewing extended the mercerized thread beyond its primary or secondary creep point; therefore, there was less variation in tension during sewing and more uniformity in the number of stitches.

Soft thread, being more elastic, underwent reoccurring extension by the sewing action of the machine resulting in a greater variation in the number of stitches it made. This was confirmed by the data on cumulative extension of soft and mercerized threads on Table III.

The samples were laundered five times in accordance with AATCC Method

88B. After the final drying, the distance between the marks was re-measured. The results are shown in Table V.

Table V

LENGTH OF SEAMS AFTER WASHING (IN INCHES)

70/2 Soft Thread			70/2 Merc. Thread		
Belfast	Permafresh	Untreated	Belfast	Permafresh	Untreated
13.69	13.75	13.38	13.69	13.75	13.38
13.75	13.75	13.38	13.69	13.75	13.38
13.69	13.75	13.31	13.69	13.75	13.38
13.69	13.75	13.44	13.69	13.75	13.38
13.69	13.75	13.38	13.75	13.69	13.38
13.56	13.81	13.38	13.75	13.62	13.38
Mean					
13.67	13.76	13.38	13.70	13.72	13.38
Percent Contraction					
2.32	1.70	4.47	2.10	2.01	4.47

As had been expected, the untreated broad cloth contracted most, followed by the Belfast and Permafresh broad cloth in that order.

A comparison of these results with those obtained by laundering unsewed samples showed that all three sewed samples contracted from 1.5 to 1.7 percent more than their unsewed counterparts. This additional contraction was attributed to the contraction of the sewing thread.

Dorkin and Chamberlain's technique was used in earlier work to measure the differences in the contraction and extension of soft and mercerized threads (See page 9, Table II, Quarterly Report 3). This technique showed that mercerized thread changed dimension less than soft thread.

These later tests using sewed samples established that seams sewed with mercerized thread contracted more than those sewed with soft thread. The explanation of these observations lay in the resistance of the yarn systems to the attempted contraction of the sewing thread. Soft thread being more elastic, less tension was required to extend it, and the resistance of the yarn systems to contraction of the thread was sufficient to cause extension of the soft threads.

Mercerized thread being less elastic could not respond to the yarn tensions, and the seam and thread both contracted. Therefore, the inability of the mercerized thread to respond as readily as the soft thread to the change in tensions in the yarn systems caused the mercerized thread samples to pucker as badly after laundering as the soft thread samples (see page 18, Table IV, Quarterly Report 5).

D. Evaluation of experimental threads

1. Threads treated with film forming agents and semi-durable swelling agents

A lot of twelve cones was submitted by Coats & Clark, Inc., using their Wolf quality thread (100 percent American cotton), Ticket No. 70/2, soft finish. Six cones of thread were finished with film forming agents which have similar elastic properties to cotton and are readily removed after sewing. Four cones were finished with semi-durable swelling agents which are readily removed by extraction after sewing. Two cones were left untreated for control. These thread treatments are described below:

Treatment	Source	Type agent
Elvanol 51-05 (polyvinyl alcohol - PVA)	DuPont	Film forming
Elvacet 81-900 (polyvinylacetate - PVAC)	DuPont	Film forming

(continued)

Treatment	Source	Type agent
Polyox WSR-N-10 (ethylene oxide polymers)	Union Carbide	Film forming
Triton B (Benzyltrimethylammonium hydroxide)	Miles Chemical Corp.	Semi-durable swelling
Methyl Carbitol	Union Carbide	Semi-durable swelling

2. SRRL slack mercerized and restretched threads

The second lot of experimental threads was submitted by the Southern Regional Research Laboratory (SRRL) in New Orleans. This lot consisted of twenty-eight cones of Coats & Clark Wolf quality thread, Ticket No. 70/2, soft finish. These threads were prepared to examine a combination of the following variables on seam pucker: scouring, slack mercerization and re-stretching to various percentages of the original length, re-winding and treatment with DMEU.

These thread treatments are listed as follows:

Yarn No.	Treatment	
1	Scoured	
2	Scoured	3% DMEU treated
15	Scoured mer. slack (44")restretched (47")	
16	Scoured mer. slack (46")restretched (49")	
17	Scoured mer. slack (46")restretched (51")	
3	Scoured mer. slack (44")restretched (47")	3% DMEU treated
4	Scoured mer. slack (46")restretched (49")	3% DMEU treated
5	Scoured mer. slack (46")restretched (51")	3% DMEU treated
23	Mer. slack (44") restretched (47") scoured rewound	
24	Mer. slack (46") restretched (49") scoured rewound	
25	Mer. slack (46") restretched (51") scoured rewound	

Yarn No.	Treatment	
6	Mer. slack (44") restretched (47") scoured rewound	3% DMEU treated
7	Mer. slack (46") restretched (49") scoured rewound	3% DMEU treated
8	Mer. slack (46") restretched (51") scoured rewound	3% DMEU treated
12	Mer. slack (44") restretched (47") scoured not rewound	
13	Mer. slack (46") restretched (49") scoured not rewound	
14	Mer. slack (44") restretched (51") scoured not rewound	
9	Mer. slack (44") restretched (47") scoured not rewound	3% DMEU treated
10	Mer. slack (46") restretched (49") scoured not rewound	3% DMEU treated
11	Mer. slack (46") restretched (51") scoured not rewound	3% DMEU treated
18	Greige	
19	Greige	3% DMEU treated
26	Mer. slack (44") restretched (47")	
27	Mer. slack (46") restretched (49")	
28	Mer. slack (46") restretched (51")	
20	Mer. slack (44") restretched (47")	3% DMEU treated
21	Mer. slack (46") restretched (49")	3% DMEU treated
22	Mer. slack (46") restretched (51")	3% DMEU treated

3. Threads treated with special lubricants

The third lot of threads was submitted by the American Thread Company. These threads were prepared to compare the contribution of two commercial lubricants to seam pucker. This lot consisted of eight cones of thread, Ticket No. 70/2. Four cones were soft finished and four were given a standard mercerization finish. Two cones each of soft and mercerized threads were finished with a commercial lubricant designated "B", and two of each were finished with a commercial lubricant designated "P". The treatments are listed as follows:

Soft T32-1264B

Merc. T32-1235B

Soft T32-1256P

Merc. T32-1235P

4. Evaluation methods

These three lots of thread were evaluated by the test methods established earlier in this research. Test procedures and results are discussed in the following paragraphs.

5. Predetermination of thread sewability

Earlier work on this project has showed that there is a positive relationship between work of rupture (the integration of breaking strength and elongation factors) and abrasion resistance of thread and the ability of thread to be sewed at high speeds. It was reported in Quarterly Report 7, page 18, that threads with an abrasion resistance of approximately seven cycles and above and a work of rupture of 28 pound inches and above would sew satisfactorily at high speeds. This technique was applied to the threads evaluated this quarter.

Table VI contains the work of rupture and abrasion resistance of each of the threads. Threads that fell below the minimum standards for predicted sewability are designated (*).

6. Thread sewability

Actual sewability tests were made on each of the experimental threads. Sewability was judged by the ability of the thread to sew balanced stitches at commercial speeds over a prolonged period of sewing.

The machine was optimized for sewing balanced stitches for each thread using the lightest tension possible for minimum puckering. Sewing was done at 12 stitches per inch (SPI) and at a speed of 4800 RPM. The test threads were sewed into two thicknesses of a continuous test fabric to maximize the sewing conditions. The number of thread breaks in 15 minutes of sewing were recorded for each thread. If more than three breaks occurred, it was considered that the thread would not sew. Results are recorded in Table VI.

The work of rupture and abrasion resistance values of the Coats & Clark threads treated with film forming agents and semi-durable swelling agents tested indicated the probability of good sewability. A period of one month passed before actual sewability tests were made. It was found that all the threads would sew except the thread treated with Triton B. The work of rupture and abrasion resistance tests were repeated (see Table VI). It was found that the physical characteristics of the Triton B thread had been degraded to the point that the thread would not sew. In the other threads, some characteristics improved while others deteriorated slightly but not to the degree that sewability was affected. A further explanation of these results will be included in the final report.

As established earlier, it was found that threads with poor predicted sewability would not sew. However, ten threads with good predicted sewability would not sew without breaking excessively. These threads are being studied to explain these results. Further data will be included in the final report.

7. Evaluation of thread performance in reducing seam puckers

Two samples of Permafresh broad cloth were sewed with the untreated and treated versions of each thread that would sew according to the previous sewability test. These samples were prepared according to the standard procedure established in Quarterly Report 4, page 2, with seams sewed in the warp direction only for maximum performance. Machine settings were optimized for sewing each test thread.

The samples were evaluated by three observers using the overhead evaluation procedure described in AATCC Method 88B. Photometric tracings were made of a random three-inch segment of one seam on each sample.

Samples were laundered in accordance with the Washing Procedure II and Drying Procedure A of AATCC Method 88A.

The laundered samples were reinspected and evaluated by the same three inspectors using the overhead evaluation technique. Results of the evaluations before and after laundering are recorded in Table VI.

Photometric tracings were made of the same three-inch segments of the samples after washing. An analysis of these tracings will be included in the final report.

Of the threads evaluated this quarter, only those treated with polyvinyl acetate and Polyox produced samples which rated 3; all others had lower ratings.

The after-laundering evaluation showed that puckering intensified in all samples. Samples sewed with the polyvinyl acetate and Polyox treated thread had decreased to 1 or 2. Therefore, none of the threads evaluated this quarter showed promise in reducing seam pucker.

Table VI

PHYSICAL EVALUATIONS OF THREADS TREATED WITH FILM FORMING AGENTS AND SEMI-DURABLE SWELLING AGENTS, SRRL SLACK MERCERIZED THREADS AND THREADS TREATED WITH SPECIAL LUBRICANTS

Thread Treatment	Work of Rupture (lb. in)	Retest	Abrasion Resistance (cycles)	Retest	Sew-ability	Visual Rating(av) Before Washing	After Washing
Coats & Clark Threads							
PVA, cone 1	58.2	(73.6)	19.1	(15.9)	Will sew	2-3	1-2
cone 2	58.0	(68.7)	18.0	(14.7)	Will sew	2	1-2
PVAC, cone 1	53.4	(63.4)	12.8	(14.3)	Will sew	2-3	1-2
cone 2	43.7	(62.5)	14.7	(13.8)	Will sew	3	1
Polyox, cone 1	43.2	(51.4)	17.8	(13.1)	Will sew	3	2
cone 2	40.0	(54.3)	21.1	(10.8)	Will not sew	-	-
Triton B, cone 1	53.8	(45.1)	11.3	(2.2)*	Will not sew	-	-
cone 2	55.4	(41.6)	9.8	(1.5)*	Will not sew	-	-
Methyl Carbitol							
cone 1	57.0	(70.7)	16.8	(14.4)	Will not sew	2-3	1-2
cone 2	54.6	(64.0)	10.8	(10.8)	Will sew	2	1
Control, cone 1	58.3	(58.3)	8.8	(8.8)	Will sew	2-3	1
cone 2	58.0	(58.0)	13.8	(13.8)	Will sew	2	1-2

Table VI (Continued)

Thread Treatment	Work of Rupture (lb.in.)	Abrasion Resistance (cycles)	Sew-ability	Visual Rating(av) Before Washing	After Washing
SRRL Threads					
1	71.7	9.3	Will sew	1-2	< 1
2	31.5	1.0*	Will not sew	-	-
15	110.0	24.8	Will sew	2	1
16	96.1	16.9	Will sew	2	< 1
17	88.8	13.3	Will sew	2	< 1
3	79.9	12.3	Will not sew**	-	-
4	59.2	5.3*	Will not sew	-	-
5	53.7	5.9*	Will not sew	-	-
23	101.4	16.9	Will sew	2	< 1
24	94.8	18.1	Will sew	2	< 1
25	76.7	16.1	Will sew	1-2	< 1
6	64.8	12.8	Will not sew**	-	-
7	62.0	5.7*	Will not sew	-	-
8	57.1	6.9*	Will not sew	-	-
12	100.4	20.3	Will sew	2	< 1

Table VI (Continued)

Thread Treatment	Work of Rupture (lb.in.)	Abrasion Resistance (cycles)	Sew-ability	Visual Rating(av) Before Washing	After Washing
(SRRL Threads - continued)					
13	84.3	21.4	Will sew	2	< 1
14	66.6	10.7	Will sew	1	< 1
9	71.9	6.3*	Will not sew	-	-
10	69.2	9.4	Will not sew**	-	-
11	48.6	9.8	Will not sew**	-	-
18	58.8	14.2	Will sew	2	1
19	49.2	9.5	Will not sew**	-	-
26	96.5	29.6	Will sew	2	< 1
27	87.4	24.4	Will sew	2	1
28	71.3	24.6	Will sew	2	1
20	68.7	9.1	Will not sew**	-	-
21	69.9	12.4	Will not sew**	-	-
22	62.6	10.8	Will not sew**	-	-
American Threads					
Soft T32-1264B cone 1	40.2	15.5	Will not sew***	3	1
cone 2	32.8	5.8*	Will not sew	-	-

Table VI (Continued)

Thread Treatment	Work of Rupture (lb.in.)	Abrasion Resistance (cycles)	Sew-ability	Visual Rating(av) Before Washing	After Washing
Merc. T32-1235B					
cone 1	34.8	16.2	Will sew	1	< 1
cone 2	34.7	13.8	Will sew	-	-
Soft T32-1256P					
cone 1	30.7	11.3	Will sew	-	-
cone 2	39.5	17.3	Will sew	2-3	1
Merc. T32-1235P					
cone 1	37.8	10.7	Will not sew	*** 3	1
cone 2	27.7*	7.7	Will not sew	-	-

* Factor believed to cause poor sewability.

** Threads predicted to have good sewability but broke excessively when tested.

*** Samples sewed at reduced speed.

\- No samples were sewed and rated.

III. FUTURE PLANS

A final report summarizing the findings of this research will be prepared and submitted during the next quarter.

A proposal for follow-on research into the physics of seam pucker in all-cotton durable press fabrics has been submitted to the SRRL separately.

FINAL REPORT

PROJECT A-786

PHYSICS OF SEAM PUCKER

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CHIN T. KWON
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SOUTHERN UTILIZATION RESEARCH AND DEVELOPMENT DIVISION
NEW ORLEANS, LOUISIANA

ABSTRACT

This report completes two years of research into the basic physics of seam pucker and the possibilities of treating cotton thread to minimize its contribution to this pucker. The data accumulated during the research were analyzed with the result that it appears that three factors contribute 76 percent of the predilection to pucker. These are sewing direction, number of stitches per inch, and dimensional compatibility of components being sewed together. Although laundering does intensify some forms of puckering, fabric finish itself is not a major factor and the three major factors remain chiefly responsible. Whether these factors could be detected and measured during production sewing seems improbable if inspection depends on the present AATCC visual rating system. A photometric system devised during this research shows promise of more objective ratings than now possible. Threads play a relatively minor role in pucker. None of the treatments tried combined both sewability and improved after laundering performance. It appears that further work to stabilize the threads with a mixture of resins which dispose to different portions of the cross-section of the thread is warranted. None of the other approaches to thread treatment or finish show sufficient promise to warrant continued study at this time. Recommendations for follow-on on research have been submitted to the sponsor separately.

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I. INTRODUCTION

A. Background

1. This is the final report on this project. It brings together the results of two years work along the two lines of research specified in this contract. These were:

   a. The basic physics of seam pucker as it occurred in wash wear cotton fabric sewed with cotton thread.

   b. Examination of various treatments and finishes for cotton thread which might reduce the tendency to pucker when these threads are sewed into cotton wash wear fabrics.

2. The large amount of data which was accumulated during the research lent itself to analysis by computer. The research team had access to both a Burroughs B-220 and a B-5500 computer. Programs were prepared for both computers plus extensive calculation using desk calculators. The purposes of these analyses were to:

   a. Determine whether any single factor had greater influence on the occurrence of pucker than the other factors did.

   b. Determine the nature and number of factors which made the major (over 67 percent) contribution to pucker formation.

   c. Determine whether these factors were consistent for both before and after laundering. (That is for example, was there a factor which existed only after laundering but was the principal cause for consumer rejection as contrasted to passage as acceptable immediately after sewing.)

   d. Determine whether any single thread treatment combined acceptable sewability with reduction in the occurrence of after laundering pucker. If none was found, what was the best alternative.

B. Design of the Analyses

1. For the basic physics of seam pucker:

   a. Study the factors recorded for each test sample sewed during the research. Determine any relationships.

   b. Study the same six factors used in analyzing test samples which were rated by both visual and photometric methods. Determine any correlations in the variation in seam pucker observed by these methods.

Validate relationships between the results of two methods.

c. Compare the results obtained in these two studies and draw conclusions.

2. For the effect of various treatments on thread:

a. Study the results of sonic fatigue test.

b. Study the results of plotting the Work of Rupture and Abrasion Resistance of threads before treatment, after treatment, and after curing where appropriate.

c. Relate this study to actual test sewing of threads.

d. Relate this study to disposition of resin on thread where appropriate.

e. Compare the results obtained in these four studies and draw conclusions.

II. STATISTICAL ANALYSES

A. The Relationship Between Photometric Tracing Method and Visual Rating Method

1. As pointed out in Quarterly Report 5, page 31, although it was only discussed briefly for the selected specimens, the relationship between the photometric tracing and visual rating methods should be analyzed in detail. The visual rating method specified in AATCC Test Method 88B, which was the prescribed method of grading seam pucker, depended upon the subjective judgment of the observers. The photometric tracing device was developed to provide an objective method of evaluation which would be exact and reliable.

2. The relationship between the photometric tracing and the visual rating was statistically calculated using the least-squares regression analysis. The visual rating was assumed to be an independent variable and the tracing, a dependent variable. The average of three ratings for each specimen was calculated as a fraction and the traced value (the ratio of the length of the traced curve to that of a straight line in the same unit of time) was classified into each average rated class. The relationship between these two grading systems was assumed to be curvilinear since the visual rating classes were equally divided, and the change of the traced value was not linearly proportional to that of the visual rating class. This relationship was assumed to be expressed in the formula:

$$Y = a + bX + cX^2$$

where Y = the photometrically traced value

X = the visually rated class

a, b, and c are constants.

The constants a, b, and c were determined by solving the following three equations simultaneously:

$$(\Sigma x^2)b + (\Sigma xu)c = \Sigma xy$$

$$(\Sigma xu)b + (\Sigma u^2)c = \Sigma uy$$

$$a = M_y - b(M_x) - c(M_u)$$

where n = sample size

$$M_x = \frac{\Sigma X}{n} \qquad \Sigma u^2 = \Sigma X^4 - nM_u^{\ 2}$$

$$M_y = \frac{\Sigma Y}{n} \qquad \Sigma xy = \Sigma XY - nM_xM_y$$

$$M_u = \frac{\Sigma X^2}{n} \qquad \Sigma uy = \Sigma X^2Y - nM_uM_y$$

$$\Sigma X^2 = \Sigma X^2 - nM_x^{\ 2}$$

$$\Sigma Xu = \Sigma X^3 - nM_xM_u$$

The derived equation is:

$$Y = 1.653 - 0.185X + 0.0134X^2$$

Ninety-five percent confidence limits were calculated and are as follows:

$$Y_{calc.} \pm 0.052$$

where $Y_{calc.}$ = calculated value from the derived equation.

The index of correlation was calculated as follows:

$$S_y = \sqrt{\frac{\Sigma Y^2 - nM_y^2}{n}}$$

$$S_z = \sqrt{\frac{\Sigma X^2 - nM_z^2}{n}}$$

where $Y = Y_{real}$

$Z = Y_{real} - Y_{calc.}$

$M_z = \frac{\Sigma Z}{n}$

$$i_{yx}^2 = 1 - \frac{S_z^2}{S_y^2} = 0.7936$$

where i_{yx} = index of correlation

$$i_{yx} = 0.89 \quad .$$

3. The index of correlation indicated the coefficient of correlation between the visual rating (X) and the photometric tracing (Y) when values of Y were estimated from values of X according to the fitted-curve equation. The calculated value of the index of correlation as .89 indicated that almost perfect correlation between X and Y existed, considering the inaccuracy of visual rating.

4. Figure 1 shows the relationship between these two grading systems. Most of the average values of tracing existed within the 95 percent confidence limits and this curve was best fitted for the data. If this tracing method could be accepted for grading seam pucker, the photometrically traced values for each rating class would be:

Rating Class	Estimated Trace Value
less than 1	greater than 1.522
1	1.443 - 1.522

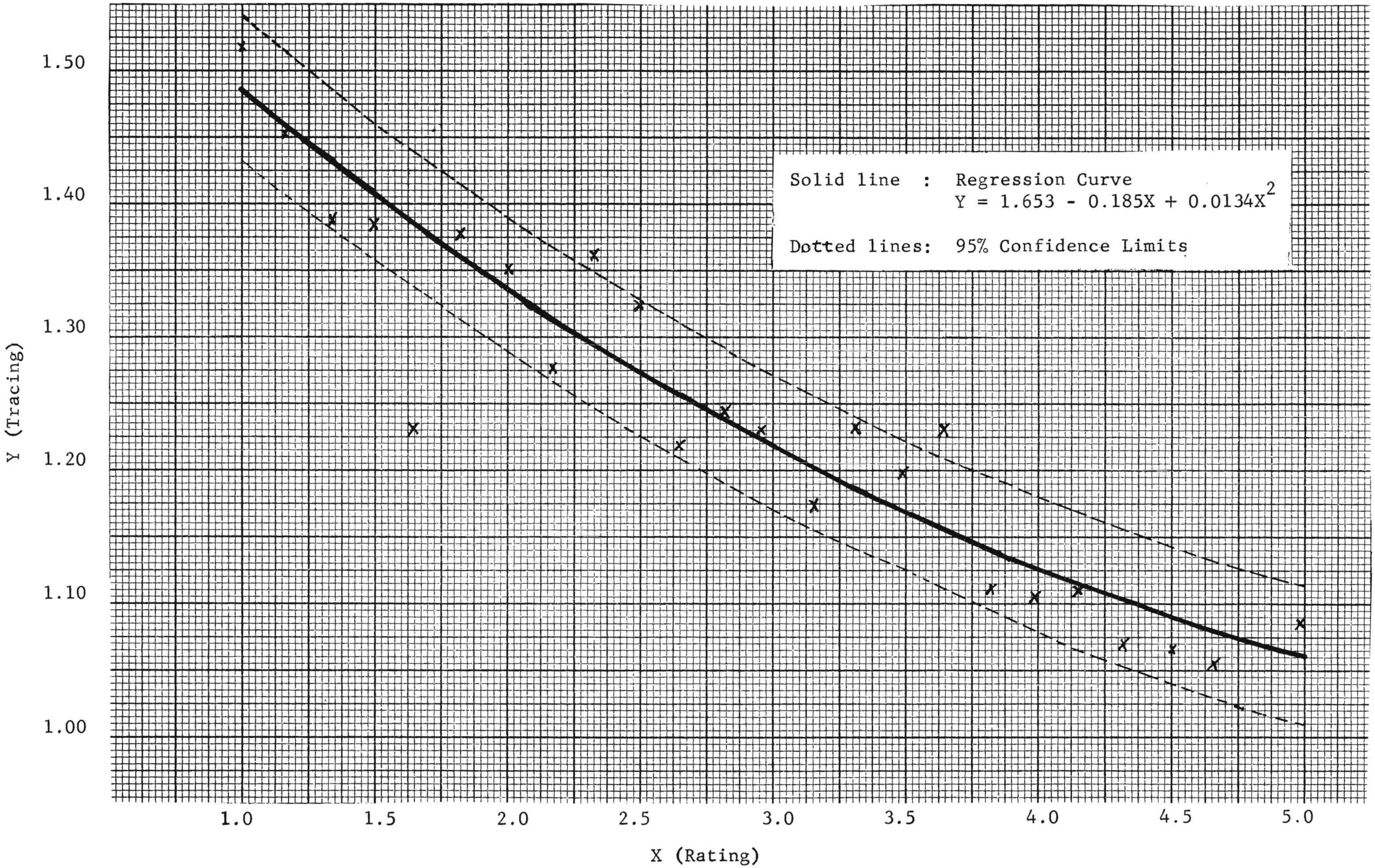

Figure 1 Regression Curve in Rating and Tracing

1-2	1.370 - 1.443
2	1.305 - 1.370
2-3	1.246 - 1.305
3	1.193 - 1.246
3-4	1.148 - 1.193
4	1.109 - 1.148
4-5	1.077 - 1.109
5	less than 1.077

B. Analysis of the Factors Involved in the Variance of Seam Pucker as Measured by Visual Rating and Photometric Methods

1. A program to analyze these data was written for the Burroughs Algol B-220 computer (see Appendix A). This program, which was based on factorial design, used the results obtained by the Visual Rating-Photometric Methods as inputs to determine the correlations which existed between the six factors.

2. The six factors used as inputs, both before and after washing were:

(a) Finish on cloth
(b) Finish on thread
(c) Size of thread
(d) Stitches per inch
(e) Type of seam
(f) Sewing direction

3. Table I shows the results obtained.

4. This analysis was incomplete in that the nature of the variance among factors and between before and after washing was not conclusive and did not consider the higher order interactions (above the second order). The data obtained by the photometric tracing method were analyzed further with the results shown in Table II.

5. It was determined that most of the variance of seam pucker was caused by the factor of sewing direction before and after washing. The other factors were only minor causes of seam pucker before washing. These percentages do not mean the fractions of the amount of seam pucker caused by each factor but rather the fractions of the variance of seam pucker. The fraction of the variance of seam pucker may be eliminated by controlling the effect of each factor.

Table I. A B-220 Computer Comparison of the AATCC Visual Rating System and the Photometric Tracing Method.

Between Factors	Before Washing		After Washing and Drying	
	From Rating	From Tracing	From Rating	From Tracing
Finish on cloth	Resin treated > untreated	Resin treated > untreated (BPC APC)	Uncertain	No significant difference
Finish on thread	Mercerized > soft	Mercerized > soft	Mercerized > soft	No significant difference
Size of thread	Finer thread > coarser thread (100/2 > 80/2, 70/2) x1	No significant difference	Uncertain x2	100/2 > 70/2
Number of SPI	10 SPI > 12 SPI > 14 SPI > 16 SPI >	12 SPI > 16 SPI	Uncertain x3	No significant difference
Type of seam	French > flat (a little diff.)	Flat > French	French > Flat	French > Flat
Sewing direction	Bias > filling > warp	Bias > filling > warp	Bias > filling warp	Bias > filling warp

x1 Little difference between 70/2 and 80/2.

x2 Soft thread, finer thread > coarser thread (100/2 > 80/2 > 70/2)
Merc. thread coarser > finer (100/2 > 80/2 > 100/2)

x3 Untreated cloth, high number of SPI > low number of SPI (16 SPI > 12 SPI)
Resin treated cloth, lower number of SPI > high number of SPI (12 SPI > 16 SPI)

> Symbol signifying better than, or less puckering

Table II. Components of Variance Before and After Washing

Factor	Before Washing Variance	Before Washing %	After Washing Variance	After Washing %
Direction of sewing	0.6102	75.6	16.7140	93.8
Type of seam	0.0518	6.4	0.8748	4.9
No. of SPI	0.0718	8.9	-	-
Size of thread	-	-	-	-
Finish on thread	0.0302	3.8	-	-
Finish on cloth	0.0243	3.0	-	-
Error	0.0185	2.3	0.2229	1.3
Total:	0.8068	100.0	17.8117	100.0

6. The change of the variance of seam pucker upon washing depended on the factors and the effect of sewing direction was the most pronounced among the factors. A detailed numerical analysis of the change of the variance upon washing is included in Table III.

7. Using the ratio of index value obtained after washing to that obtained before washing, the change of seam pucker upon washing was analyzed in detail to determine the degree to which the occurrence of puckering depended upon the effect of washing.

8. The ratio of index value was calculated for all the specimens and analyzed with six variables, which were selected for study earlier, by the analysis of variance, the completely randomized factorial design. In doing this, it was assumed that the second or higher order interactions did not exist.

9. Table III shows the significance of the effects of each factor and the first order interaction on the change of seam pucker upon washing.

10. As shown in Table III, the most important factors which affected seam pucker upon washing were sewing direction (A), type of seam (E), and the interaction of sewing direction and finish on fabric (A and F). These three factors caused 76 percent of total variance and 13.1 percent of total variance was caused by the second or higher order interactions (42 interactions) and random error. This meant that three quarters of the total variance might be reduced by eliminating the effects of three factors of sewing direction, type of seam, and interaction of sewing direction and finish on fabric.

11. Further analysis of the factors by Duncan's multiple range tests at 5 percent significance level showed that the significant difference between variables was as follows:

a. Factor A - Sewing direction

(1) Bias sewing caused the least change in pucker, sewing in filling direction followed it and sewing in warp direction caused the greatest change in pucker.

b. Factor B - Thread size

(1) There was no significant difference in the change of pucker upon washing between the specimens sewed with 70/2 and 80/2 sewing thread, but 100/2 sewing thread caused significantly less change.

Table III. Effect of Factors on the Change of Seam Pucker Upon Washing and the Components of Variance.

Factor		Significance at 5% Level	Comp. of Variance Variance	%
Sewing Direction	- A	Highly significant	0.11117	45.5
Thread Size	- B	Significant	0.00151	0.6
Stitches per Inch	- C	Slightly significant but not at 1%	0.00050	0.2
Thread Finish	- D	Not significant	-	-
Type of Seam	- E	Highly significant	0.02481	10.1
Fabric Finish	- F	Significant	0.00332	1.4
Interactions				
A and B		Not significant	-	-
A and C		Slightly significant but not at 1%	0.00143	0.6
A and D		Not significant	-	-
A and E		Significant	0.00379	1.6
A and F		Highly significant	0.04923	20.1
B and C		Not significant	-	-
B and D		Not significant	-	-
B and E		Not significant	-	-
B and F		Significant	0.00756	3.1
C and D		Not significant	-	-
C and E		Significant	0.00267	1.1
C and F		Slightly significant but not at 1%	0.00122	0.5
D and E		Not significant	-	-
E and F		Slightly significant but not at 1%	0.00115	0.5
E and F		Significant	0.00386	1.6
Error and Second or higher order interactions			0.03210	13.1
Total		-	0.24432	100.0

This could be explained by the measurement of the average thickness of sewing thread as shown on page 8. The difference of diameters of sewing thread between ticket numbers 70/2 and 80/2 was only 0.0089 mm, but the difference between 80/2 and 100/2 was 0.0221 mm which was much larger than that between 70/2 and 80/2.

c. Factor F - Finish on fabric

(1) There were significant differences in the change of seam pucker where the three types of fabrics were washed together with untreated fabric. Permafresh treated fabric showed the least change and untreated fabric the most change.

d. Factors A and F interacting (sewing direction and finish on fabric)

(1) The effect of nine possible combinations (three sewing directions x three types of fabric) was analyzed and showed the following results. Although there was no significant difference between combinations of filling sewing-Belfast treated fabric and filling sewing-Permafresh treated fabric, the differences among the other combinations were much more significant. In descending order of satisfactory performance the combinations which caused the least effect on the change of seam pucker upon washing were:

bias sewing	- Permafresh fabric--most satisfactory
bias sewing	- Belfast fabric
bias sewing	- Untreated fabric
filling sewing	- Untreated fabric
filling sewing	- Belfast fabric
filling sewing	- Permafresh fabric
warp sewing	- Permafresh fabric
warp sewing	- Belfast fabric
warp sewing	- Untreated fabric--least satisfactory

(2) This fact could be explained by the contraction or extension of fabric after washing. As shown in the table (Table 4 on page 14, Quarterly Report 5), none of the three types of print cloth contracted in the warp direction upon washing but did contract in the filling direction. A certain amount of contraction of fabric reduced the change in seam pucker, since the sewing thread in the seam tended to contract upon washing. In the filling direction sewing the untreated print cloth contracted the most and

Permafresh treated print cloth contracted the least, and the effect of combination of filling sewing-untreated fabric was less than those of combinations of filling sewing-Belfast and Permafresh treated fabric. This meant that the amount of contraction of seam caused only by sewing thread was close to that of the untreated fabric sewed in the filling direction, 3.75 percent. Then, the combinations of filling direction-Belfast and the filling direction-Permafresh treated fabric followed it in order.

12. These results correlated closely with those reported in Paragraph 1A.

C. Determination of Second and Higher Order Interactions

1. After completing the analysis of the results of the six factorial design program using the B-220 computer, it was decided that examination of the second and higher order interactions would be necessary. To handle the interaction of 864 samples, each with six factors, before and after washing, required the larger storage capacity of the Burroughs B-5500 computer. A program to accomplish this was written, a copy of which is appended (Appendix B).

2. Separate computer runs were made as follows to array the data by:

   a. Amplitude of pucker before washing

   b. Amplitude of pucker after washing

   c. Frequency (length) of pucker before washing

   d. Frequency (length) of pucker after washing

3. This analysis confirmed the analysis made on the B-220 computer. It was found that second order interactions played a minor role in the formation of pucker. Third and higher order interactions did not have significant effects on the formation of pucker.

D. Simulation of Thread Fatigue

1. As a means of studying sewing from a dynamic view, a device was built by Mr. Chin Kwon to take advantage of the sonic modulus of the test threads. One of his major objectives was to determine the time required to rupture a test thread. A second objective in this study was to determine where the rupture would occur along the span. Quarterly Report 7, pages 4 through 8, describe the technique and equations involved in setting up this device.

Table IV. A Comparison of Sonic Fatigue and Elongation for Coats and Clark Test Threads.

Thread	Ticket #70/2 av. time to break (sec.)	Elong.	Tex.	Ticket #80/2 av. time to break (sec.)	Elong.	Tex.
Soft, untreated	109.2	7.2	32.8	87.7	7.6	29.1
Soft, DMEU, cured	14.8	6.2	33.1	5.4	6.8	30.6
Soft, DMEU, cured	4.7	6.0	32.1	13.8	5.9	29.8
Soft, triazine, uncured	13.6	5.9	33.6	11.5	6.9	30.3
Soft, triazine, cured	18.9	6.3	32.6	42.1	7.3	29.0
Merc., untreated	6.2	5.2	33.1	2.4	5.4	29.6
Merc., DMEU, cured	2.1	4.5	32.7	0.5	4.8	30.5
Merc., triazine, cured	6.3	5.0	32.5	1.7	5.3	29.6

Sixteen threads were evaluated with the results shown in Table IV.

2. An analysis of these data shows that mercerized threads and treated threads broke in a considerably shorter time than their soft version did.

3. Some of the resin treated threads broke during the initial 20 seconds of vibration. Performance was poorest on the mercerized DMEU cured thread.

4. An examination of the nature of the breaks that occurrred in the threads showed that a shearing or tearing of the fibers had occurred rather than a single complete rupture of the entire cross section of the thread.

5. During the testing period a record of the location of each break was kept and it was found that 50 percent of the breakage occurred at the speaker cone, 10 percent occurred at the jaw and 40 percent occurred at random along the remaining length of the span.

6. The higher incidence of breaks at the speaker cone agrees with the higher incidence of breaks at the interlock point which had been found during experimental sewing. It appears that these breaks are caused by the stress induced in the thread as the stitch is pulled tight. The 10 percent breakage at the jaw indicates that fewer breaks will occur at the tension or thread guide.

7. There appears to be a high correlation between this set of data and that produced by the graph of the work of rupture versus abrasion resistance.

8. The design of this instrument prevented performing true tests of dynamic simulation of elongation-fatigue as it occurs in conjunction with abrasion.

E. Work of Rupture and Abrasion Resistance as Indicators of Sewability

1. The interrelation of these two measurements in the determination of the probability that a given thread would sew was discussed in Quarterly Report 7, pages 15 to 19. Further analysis sought to determine whether these static measurements could be related to dynamic fatigue readings and to actual sewing tests.

2. Figure 2 contains the plots of all test threads using value of the Work of Rupture and Abrasion Resistance as the ordinates and abscissas for the plots.

3. It was found that the results obtained closely correlated with both dynamic fatigue and actual sewing results.

4. It appears that either of these tests would help to determine the probability of puckering and allow for adjustments to the machine and/or

working conditions before actual sewing began. It is probable that actual test sewing would be necessary in cases where threads are not clearly sewable.

F. Analysis of Effects of Various Thread Treatments

1. By taking advantage of the trigonometric function $\tan \theta = \frac{Y}{X}$, the amount of change in abrasion resistance and/or work of rupture could be calculated (see Quarterly Report 7, pages 19 through 21).

2. This method of analysis of the various treatments showed that:

   a. Tension mercerization decreased the abrasion resistance but did not change the work of rupture.

   b. Application of a resin decreased both the work of rupture and abrasion resistance of a thread.

   c. Curing affected each type of resin differently.

      (1) Curing DMEU decreased only the work of rupture.

      (2) Curing DMDHEU decreased both factors, but abrasion resistance more than work of rupture.

      (3) Curing triazine increased both factors.

   d. Slack mercerization and restretching to original length decreased the work of rupture but increased the abrasion resistance.

   e. Application of DMEU resin followed by curing of a slack mercerized thread and then restretching it to its original length produced a thread with the same properties as a tension mercerized thread treated with DMEU and cured (see Figure 2, thread numbers 4 and 19).

3. Twenty-eight different threads produced by SRRL are shown in Figure 2. The variations were achieved by interchanging scouring, slack mercerization, restretching, winding, and resin treatment and curing. The conclusions reached after analyzing these threads to determine their Abrasion Resistance and Work of Rupture were:

   a. Highest Work of Rupture and Highest Abrasion Resistance--slack mercerized and restretched.

   b. Next--scoured, slack mercerized and restretched.

   c. Next--slack mercerized, restretched, and rewound.

   d. Next--slack mercerized, restretched, scoured and rewound.

   e. Poorest--resin treated--low sewability.

4. It was noted that slack mercerization was the only process to improve both the work of rupture and abrasion resistance. All of the other processes decreased both factors. In a way, just scouring is worse than resin treating for decreasing these factors. The scoured thread, which had been resin treated and cured was the poorest case of all with absolutely no sewability. Scouring alone lowered the untreated soft thread to the same abrasion resistance range as the various resin treated threads slack mercerized.

5. Of all the resin treated threads, the one with the best sewability had been slack mercerized (44") and restretched to (47") then rewound, scoured, and treated with 3 percent DMEU and cured. This thread showed promise although it had only poor-to-fair sewability.

6. The test threads treated by Coats and Clark Company with swelling agents to increase the diameter and then be readily removable after sewing, were not very promising. Upon receiving the shipment, they were tested for abrasion resistance and work of rupture, then were not used in sewing tests for six weeks. At the time of the sewing tests those which had showed good sewability on the earlier evaluation failed to sew properly. When the abrasion resistance and work of rupture tests were repeated, the threads showed an overall decrease in properties, especially those treated with Triton B (see Quarterly Report 8, Table VI, page 29).

7. It was determined that the American Thread Company's threads were similar to the original Coats and Clark untreated threads and no further work was done on them.

8. The Dixie Yarns' threads possessed good sewability with the exception of one specially treated thread. This thread was treated with a moderate level of resin and a polypropylene softner. The addition of the softner reduced the work of rupture sufficiently to produce a poor thread. The best threads of this group were (a) the thread with the minimum level of resin, and (b) the thread with the moderate level of resin and a special lubricant.

9. In summary, the graph of Work of Rupture versus Abrasion Resistance provides two types of data:

a. An indication of sewability,

b. A comparison of thread treatments.

KEY TO FIGURE 2

Yarn No.	Treatment	
1	Scoured	
2	Scoured	3% DMEU treated
15	Scoured mer. slack (44") restretched (47")	
16	Scoured mer. slack (46") restretched (49")	
17	Scoured mer. slack (46") restretched (51")	
3	Scoured mer. slack (44") restretched (47")	3% DMEU treated
4	Scoured mer. slack (46") restretched (49")	3% DMEU treated
5	Scoured mer. slack (46") restretched (51")	3% DMEU treated
23	Mer. slack (44") restretched (47") scoured rewound	
24	Mer. slack (46") restretched (49") scoured rewound	
25	Mer. slack (46") restretched (51") scoured rewound	
6	Mer. slack (44") restretched (47") scoured rewound	3% DMEU treated
7	Mer. slack (46") restretched (49") scoured rewound	3% DMEU treated
8	Mer. slack (46") restretched (51") scoured rewound	3% DMEU treated
12	Mer. slack (44") restretched (47") scoured not rewound	
13	Mer. slack (46") restretched (49") scoured not rewound	
14	Mer. slack (44") restretched (51") scoured not rewound	
9	Mer. slack (44") restretched (47") scoured not rewound	3% DMEU treated
10	Mer. slack (46") restretched (49") scoured not rewound	3% DMEU treated
11	Mer. slack (46") restretched (51") scoured not rewound	3% DMEU treated

KEY TO FIGURE 2 (Continued)

Yarn No.	Treatment	
18	Greige	
19	Greige	3% DMEU treated
26	Mer. slack (44") restretched (47")	
27	Mer. slack (46") restretched (49")	
28	Mer. slack (46") restretched (51")	
20	Mer. slack (44") restretched (47")	3% DMEU treated
21	Mer. slack (46") restretched (49")	3% DMEU treated
22	Mer. slack (46") restretched (51")	3% DMEU treated

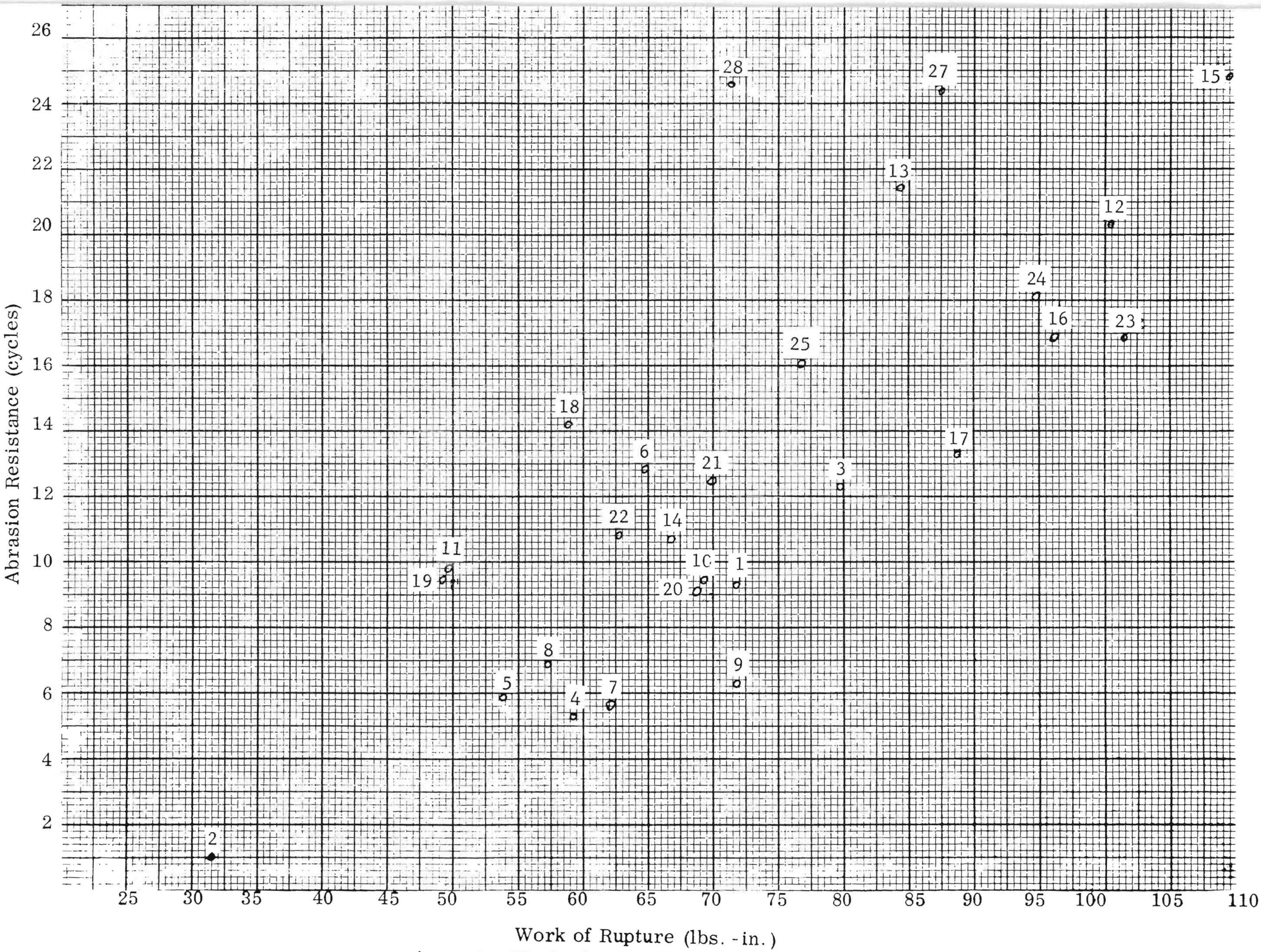

Figure 2. Work of Rupture vs. Abrasion Resistance

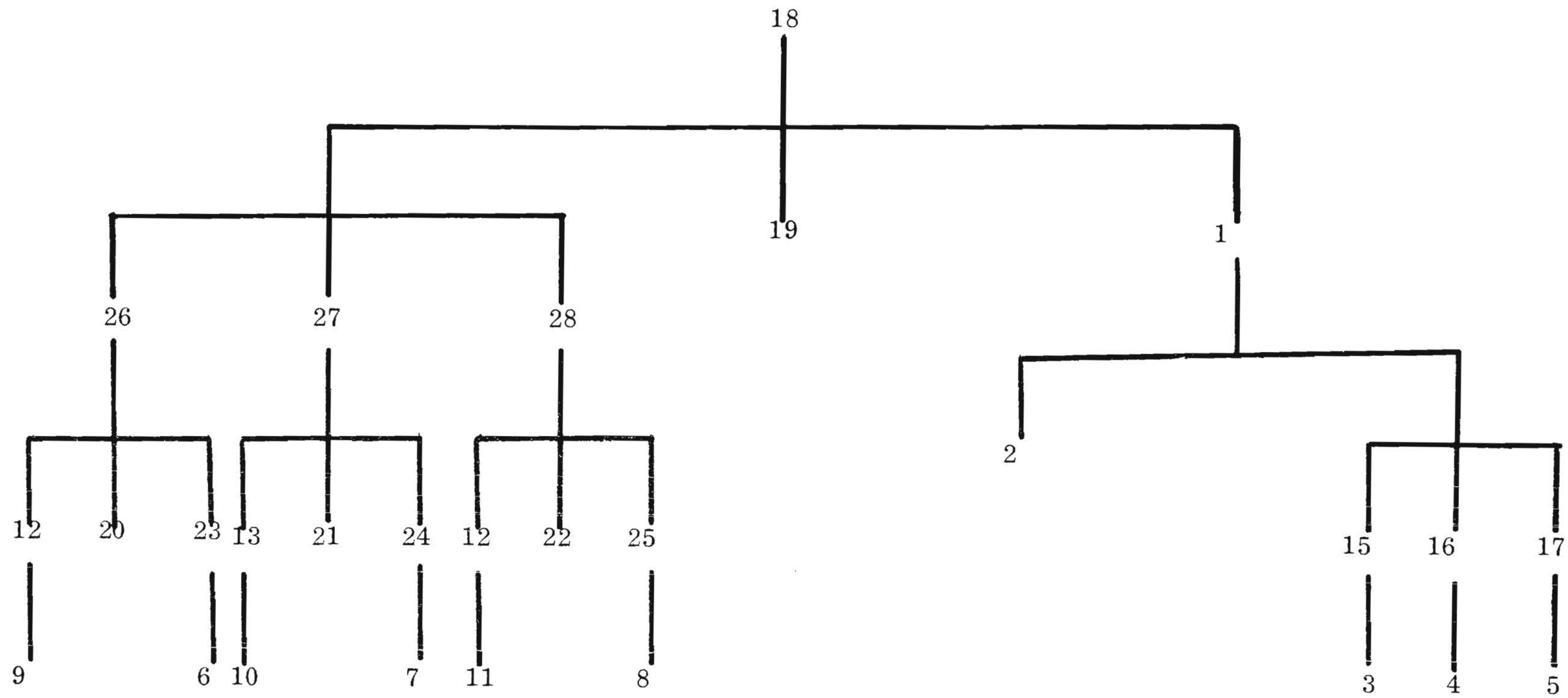

Figure 3. Flow Chart for SRRL Special Test Threads
(Note: To plot the various effects of chemical and physical treatments on the various test threads, connect the respective points as the above Flow Chart indicates.)

10. The position of a thread on the graph should not be considered an absolute guarantee of its sewability for these tests are static in nature while sewing is a dynamic operation.

G. Disposition of Resin on Thread

1. One of the major theories to stem from the various studies of resin treated threads was that the location of the resin, the type of resin, and the properties associated with that resin determined to a large extent how the resin treated threads sewed.

2. Several samples of threads treated by three different resins were used for this study. These resins were (1) DMEU, (2) DMDHEU, and (3) triazine. Each sample was tested for work of rupture and abrasion resistance, stripped of all lubricants and tested again for work of rupture and abrasion resistance. Portions were stained with a small molecular, blue acid dye and portions were hydrolyzed free of resin and tested for work of rupture. Quarterly Report 8, Table II, page 14 shows the results of stripping the lubricant and hydrolysis of the resin. The acid dye did not stain the cotton, only the resin.

3. Those threads treated with DMEU and triazine resins were stained around the outside of the cotton fibers with little or no penetration within the fiber. Those treated with the DMDHEU resin were stained only within the lumen of the cotton fiber with no staining present on the surface of the fiber.

4. The presence of the resin within the lumen and not on the surface indicated that such a treated thread should have abrasion resistance near the untreated version.

5. Those threads treated and cured with triazine resin failed to cure uniformly. Sections of each triazine treated and cured thread were cured but other sections were not. The uncured version showed an even application of resin.

6. Those treated with DMEU and DMDHEU resin cured evenly.

7. The triazine treated but uncured threads did not sew well. The cured versions showed promise of good sewability, although their sewability was low. None of the DMEU treated threads would sew. Only those DMDHEU treated possessed good sewability.

8. From this, it was concluded that the location of the resin <u>did</u> affect the abrasion resistance, one of the prime factors of sewability, of the test threads.

Table V. A Comparison of Work of Rupture, Abrasion Cycles and Sewability of All Test Threads

Thread Type & Treatment	Ticket No. 70/2		
	Work of Rupture (lbs. in.)	Abrasion (cycles)	Sewability
Original Coats & Clark Lot			
Soft untreated	40.6	10.5	will sew
Merc. untreated	40.6	7.8	will sew
Soft DMEU-uncured	31.8	3.3	will not sew
Soft DMEU-cured	29.0	3.3	will not sew
Merc. DMEU-cured	30.8	4.5	will not sew
Soft triazine-uncured	26.4	4.5	will not sew
Soft triazine-cured	36.8	9.7	will not sew
Merc. triazine-cured	34.6	8.8	will not sew
031-67-3 merc. untreated*	41.0	18.2	will sew
031-67-2 merc. treated-uncured	29.0	13.0	will sew
031-67-2 merc. treated-cured*	28.4	7.2	will not sew

* indentifies Dixie Yarns thread, untreated (031-67-3) and delay cured treated (031-67-2).

\- indicates no measurement made.

Table V. (Continued)

Tread Type & Treatment	Work of Rupture (lbs.in.)	Retest	Abrasion Resistance (cycles)	Retest	Sewability
Coats & Clark Threads					
PVA, cone 1	58.2	(73.6)	19.1	(15.9)	will sew
cone 2	58.0	(68.7)	18.0	(14.7)	will sew
PVAC, cone 1	53.4	(63.4)	12.8	(14.3)	will sew
cone 2	43.7	(62.5)	14.7	(13.8)	will sew
Polyox, cone 1	43.2	(51.4)	17.8	(13.1)	will sew
cone 2	40.0	(54.3)	21.1	(10.8)	will not sew
Triton B, cone 1	53.8	(45.1)	11.3	(2.2)*	will not sew
cone 2	55.4	(41.6)	9.8	(1.5)*	will not sew
Methyl Carbitol cone 1	57.0	(70.7)	16.8	(14.4)	will not sew
cone 2	54.6	(64.0)	10.8	(10.8)	will sew
Control, cone 1	58.3	(58.3)	8.8	(8.8)	will sew
cone 2	58.0	(58.0)	13.8	(13.8)	will sew

(continued)

Table V. (Continued)

Thread Type & Treatment	Work of Rupture (lbs.in.)	Abrasion Resistance (cycles)	Sewability	Visual Rating (av) Before Washing	After Washing
SRRL Threads					
1	71.7	9.3	will sew	1-2	< 1
2	31.5	1.0*	will not sew	-	-
15	110.0	24.8	will sew	2	1
16	96.1	16.9	will sew	2	< 1
17	88.8	13.3	will sew	2	< 1
3	79.9	12.3	will not sew**	-	-
4	59.2	5.3*	will not sew	-	-
5	53.7	5.9*	will not sew	-	-
23	101.4	16.9	will sew	2	< 1
24	94.8	18.1	will sew	2	< 1
25	76.7	16.1	will sew	1-2	< 1
6	64.8	12.8	will not sew**	-	-
7	62.0	5.7*	will not sew	-	-
8	57.1	6.9*	will not sew	-	-
12	100.4	20.3	will sew	2	< 1
13	84.3	21.4	will sew	2	< 1
14	66.6	10.7	will sew	1	< 1
9	71.9	6.3*	will not sew	-	-
10	69.2	9.4	will not sew**	-	-
11	48.6	9.8	will not sew**	-	-

(continued)

Table V. (Continued)

Thread Type & Treatment	Work of Rupture (lbs.in.)	Abrasion Resistance (cycles)	Sewability	Visual Rating (av) Before Washing	After Washing
18	58.8	14.2	will sew	2	1
19	49.2	9.5	will not sew**	-	-
26	96.5	29.6	will sew	2	< 1
27	87.4	24.4	will sew	2	1
28	71.3	24.6	will sew	2	1
20	68.7	9.1	will not sew**	-	-
21	69.9	12.4	will not sew**	-	-
22	62.6	10.8	will not sew**	-	-
American Threads					
Soft T32-1264B					
cone 1	40.2	15.5	will not sew***	3	1
cone 2	32.8	5.8*	will not sew	-	-
Merc. T32-1235B					
cone 1	34.8	16.2	will sew	1	< 1
cone 2	34.7	13.8	will sew	-	-
Soft T32-1256P					
cone 1	30.7	11.3	will sew	-	-
cone 2	39.5	17.3	will sew	2-3	1
Merc. T32-1235P					
cone 1	37.8	10.7	will not sew***	3	1
cone 2	27.7*	7.7	will not sew	-	-

* Factor believed to cause poor sewability.

** Threads predicted to have good sewability but broke excessively when tested.

*** Samples sewed at reduced speed.

- No samples were sewed and rated.

III. CONCLUSIONS

A. Minimizing Pucker

1. The three most important factors in predilection of a seam to pucker are:

   a. Direction of sewing with warpwise being the most likely to pucker, fillingwise less likely and bias least likely.

   b. Number of stitches per inch because of both increased stability of wash wear treated fabrics and the probability of yarn jamming in the relatively rigid structure.

   c. Dimensional compatability of components to be sewed together.

B. Effect of Laundering

1. Laundering intensifies pucker already present. Sewing in the warp direction is particularly bad in this respect.

2. Type of seam used is important. Flat seams pucker worse than French seams.

3. The type of fabric finish seems to have very little effect on the change in seam pucker observed after washing.

C. Thread Treatments

1. None of the test threads combined satisfactory sewability with improved after-washing performance.

2. Greatest improvement in abrasion resistance was accomplished through:

   a. Treatment with resin which was located only in the lumen of the fibers.

   b. Slack mercerization followed by restretching to less than the original length.

D. Rating Systems for Evaluating Pucker

1. The photometric system seems to give equal to or more consistent ratings than visual rating.

2. The five rating classes specified in AATCC Test Method 88B should be expanded particularly into sub-classes between 3 and 5. (It is understood that a separate study on this is in progress.)

3. The photometric device should be developed further.

E. Use of High Speed Photography

1. This technique merits further study, particularly in relating fabric geometry to sewing performance. It is probable that this factor alone contributes heavily to pucker regardless of the relative stability of the fabric and thread.

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Mr. David Fields

Dixie Yarns

Mr. Howard Seitz

U.S. Army Laboratories (Natick)

Mr. Edward Frederick

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Mr. Jerry Cogan
Dr. G. S. Hooper

Union Special Machine Company

Mr. M. M. Ambrose
Mr. Donald Myers

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Mr. Jack Crowder
Mr. Hugh McKinney
Mr. Porter Brown
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Although it is always difficult to single out individuals in a large research effort, the following merit special recognition, for they suggested main patterns for the research:

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